IPC-TR-586

Immersion Silver Plating Thickness Round Robin Investigation Data Set Compendium

March 2009

A Technical Report

Association Connecting Electronics Industries

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Immersion Silver Plating Thickness Round Robin Investigation Data Set Compendium

[For the IPC 4-14 Plating Processes Subcommittee]

Compendium Summary:

IPC 4-14 Plating Processes Subcommittee develops guidelines, test methods and techniques for evaluating process control parameters on electrolytic and electroless/immersion plating systems. The Plating Processes Subcommittee has developed the IPC-4553, *Specification for Immersion Silver Plating for Printed Boards* which sets the requirements for the use of immersion silver as a surface finish for printed boards. During a revision development phase of the specification, an investigation was initiated to understand how immersion silver plating thickness impacts solder joint integrity. The activity focused on comparing typical immersion silver plating thicknesses to extreme immersion plating thicknesses for a set of standard electronic component types used on printed boards. This technical report documents the Round Robin testing effort. The Round Robin test results were used by the 4-14 Plating Processes Subcommittee in the development of immersion silver maximum plating thickness. The Technical Report Compendium is divided into three information sets:

1. Test Vehicle Assembly Report by Celestica
2. Thermal Cycle Test Report by Rockwell Collins
3. Solder Joint Silver Content Calculations by Adtran Inc.

Compendium Acknowledgements:

The following individuals/groups were active participants in the 4-14 Plating Processes Subcommittee round robin investigation. Without their efforts, the round robin testing project would not have been possible:

- Test Plan Creation/Development: 4-14 Plating Processes Subcommittee members
- PWB Test Vehicle Contributions: Gerard O'Brien, Solderability Testing and Solutions, Inc.
- Immersion Silver Finish Contributions: 4-14 Plating Processes Subcommittee surface finish supplier representatives
- Test Vehicle XRF Measurements: Gerard O'Brien, Solderability Testing and Solutions, Inc. and Frank Ferrandino, Veeco Instruments Inc.
- PWB Test Vehicle Assembly: Gail Auyeung et al, Celestica
- Thermal Cycle Testing: David Hillman et al, Rockwell Collins
- Solder Joint Silver Content Calculations: Trevor Bowers, Adtran Inc.

Technology Assurance Laboratory
Evaluation of Immersion Silver Boards with Different Plating Thicknesses

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Revision History			
Revision:	**Created by:**	**Date:**	**Short Description**
1	Zohreh Bagheri	10/19/2006	Initial report
2	Polina Snugovsky	10/19/2006	Final edit
3			

EXECUTIVE SUMMARY

Four immersion silver plated boards were submitted to the lab for evaluation.
The boards were supplied from three different vendors with different silver thicknesses.

- Vendor A 3X SAC
- Vendor G X SAC
- Vendor D 3X Lead
- Vendor G X Lead

Five Pb-Free components were assembled on the boards using Sn-Pb and Pb-Free pastes.
More voiding as well as Champagne voiding was seen in A3X SAC and GX SAC boards.

The intermetallic layers at the component and board sides were found to be properly formed on all boards.

There was no significant difference in microstructure formed on D3X Lead and GX Lead boards.

There were more Ag_3Sn plates and they were larger in A3XSAC than GX SAC boards.

It was observed that the Pb-free balls of the BGA components were not completely mixed with the Sn-Pb paste on boards D3X Lead and GX Lead.

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1. INTRODUCTION

1.1 PRODUCT INFORMATION

Product under test:

Part Name: Imm Ag boards	**Part #:**
Description: • Vendor A 3X SAC • Vendor G X SAC • Vendor D 3X Lead • Vendor G X Lead	
Serial #s Tested: N/A	Quantity Provided: 1 each

1.2 BACKGROUND

The boards with normal plating thickness and 3X thickness were assembled with five Pb-free components as below:

- QFP208-4
- MLFP L16
- Capacitor
- PBGA 71057
- PBGA 70796

2. INSTRUMENTATION

Description	Serial Number	Calibration Due
Nikon Microscope MM-11	MG000L3144	N/A
Phoenix X-ray	C0012469	N/A
CMI X-Ray Fluorescence	C0013492	12/01/2006

3. TEST PROCEDURE

3.1 XRF

Plating thickness measurements were done on four fiducials on each board, as the other locations were soldered. An aperture size of 2x10 mil and 1/2 inch working distance was used. A spot check for calibration confirmation was performed using a 37 µin Ag standard over Cu as the base metal. (The spot check confirmed the top layer (Ag) measurement within +/-5% of the indicated thickness, per instrument spec).

3.2 *X-Ray*

Transmissive Xray examination was performed on all of the boards and components.

3.3 Cross sections

One part of each type was cut out from each board. The sections were subsequently mounted in the potting media and prepared for metallurgical observation. The preparation involved diagonal cutting on PBGA 70796 and straight cutting on all other parts followed by grinding on 120, 600, 1200 grit SiC papers. Fine polishing was accomplished using 6 and 1 micron diamond slurries. The final step involved polishing with colloidal silica to expose intermetallic particles in the bulk and intermetallic layers at the interfaces.

4. RESULTS

4.1 X-Ray

The x-ray analysis showed some voiding in the joints, and more in A3X SAC and GX SAC than D3X Lead and GX Lead. (small components like MLF L16 and the capacitors show more voiding).

4.2 XRF

Table 1 below is a summary of plating thickness measurements.

Table1. Plating thickness measurement in µin Ag.

Board ID	Fiducial 1	Fiducial 2	Fiducial 3	Fiducial 4
A3X SAC	36.9	30.8	31.3	38.0
GX SAC	14.8	13.3	12.8	13.2
D3X Lead	11.8	13.0	9.5	13.0
GX Lead	13.5	14.5	10.5	12.6

4.3 Cross-sectioning and Optical Microscopy

The microstructural observation revealed the following:

- Pb-free samples displayed a typical microstructure.
- The microstructure of the QFPs, capacitors and MLFP L16 parts of D3X Lead and GX Lead boards were typical of assemblies made using Sn-Pb eutectic paste.
- Partial mixing of SAC BGA balls with Sn-Pb paste was observed on all BGAs of D3X Lead and GX Lead boards.
- The microstructure of mixed technology joints consisted of Cu-Sn and Ag-Sn particles, Sn dendrites and interdendritic Pb phases.
- Needle-like Ag_3Sn intermetallics were found in A3X SAC and at lower levels in GX SAC. They were also larger in size in A3X SAC.
- Champagne voiding was seen in some of the joints of A3X SAC boards (specifically in MLFP L16). Figures 11, 18-24 in optical images.

5. X-ray and Optical Images

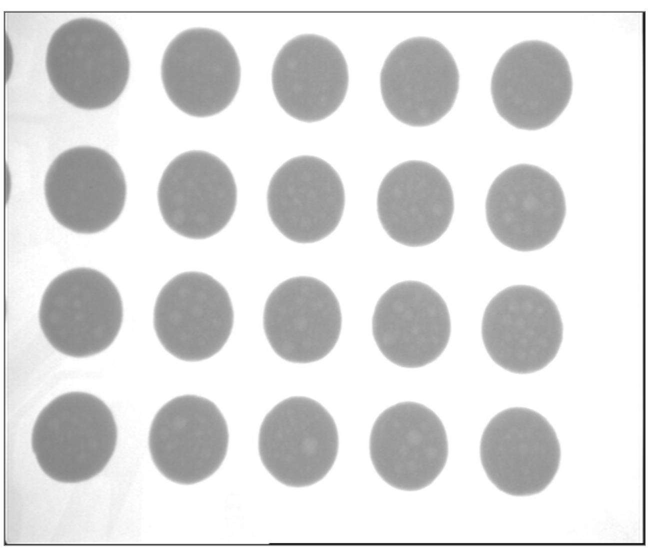


Figure 1. A3X SAC,70796,2

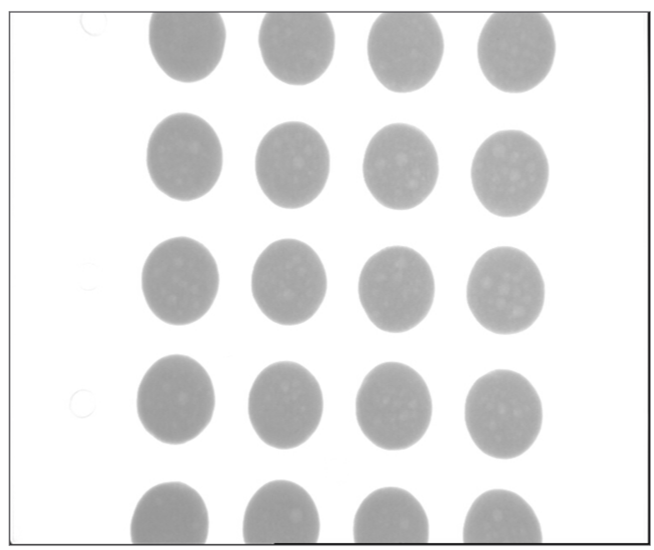


Figure 2. A3X SAC,70796

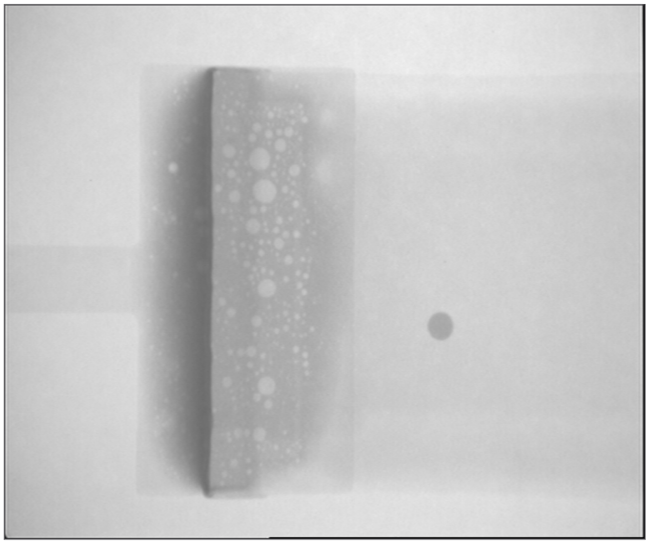


Figure 5. A3X SAC,cap,2

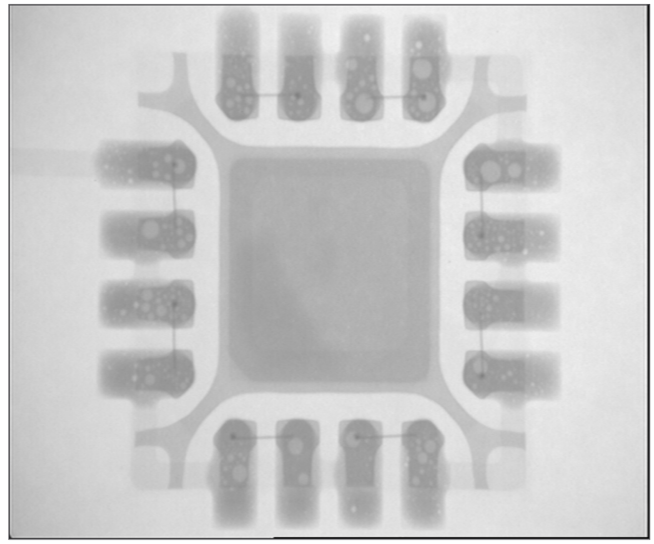


Figure 6. A3X SAC,MLFP1

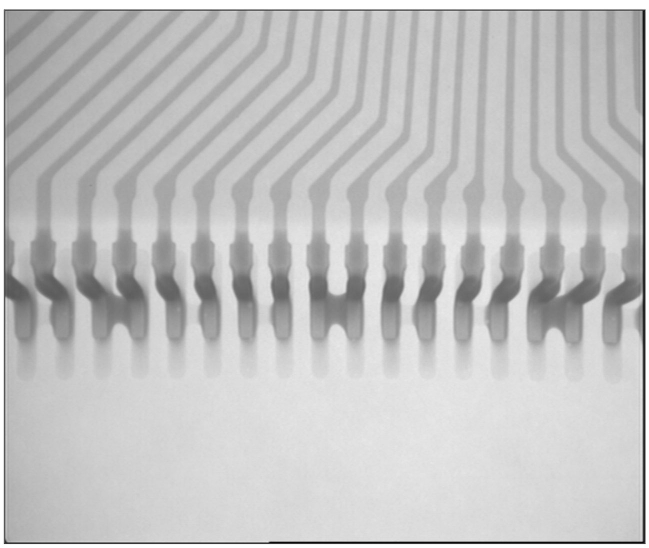


Figure 7. A3X SAC,QFP208,1

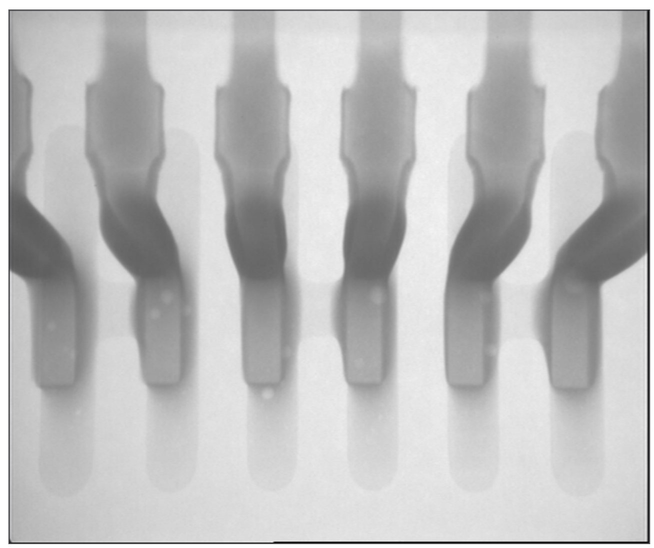


Figure 8. A3X SAC,QFP208,2

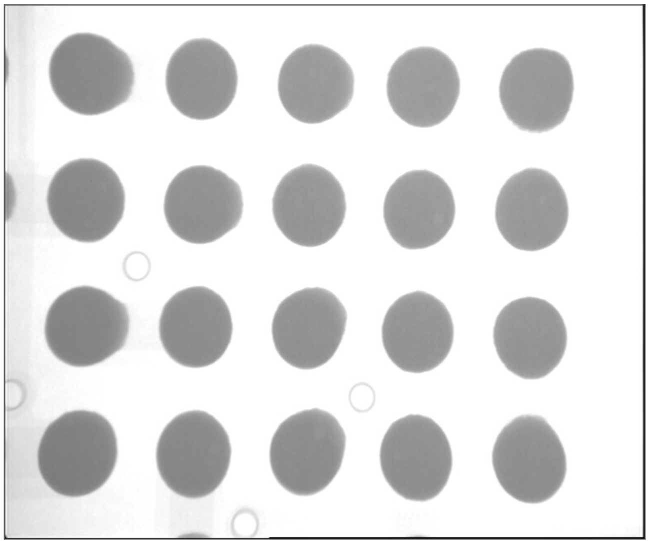


Figure 9. D3X Lead,70796

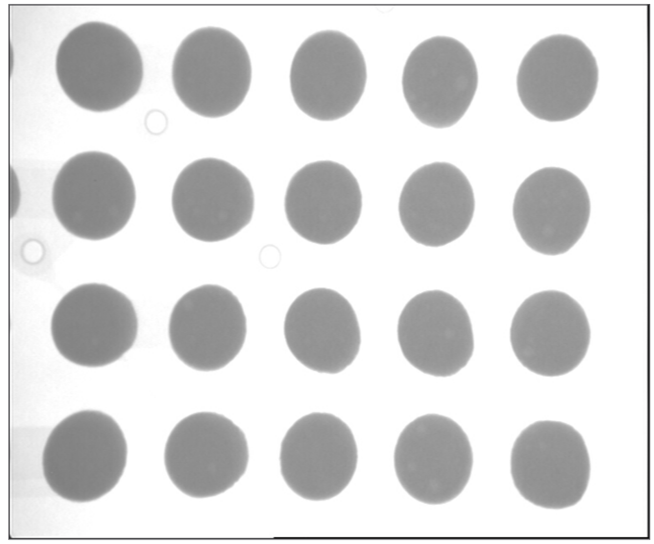


Figure 10. D3X Lead,71057

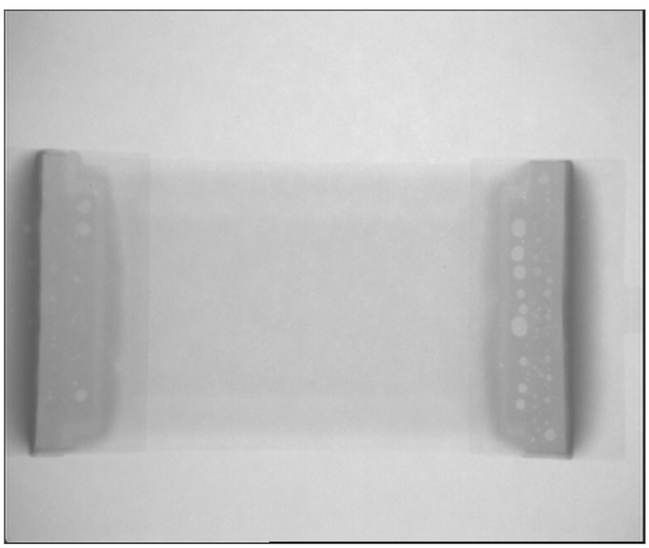


Figure 11. D3X Lead,cap,1

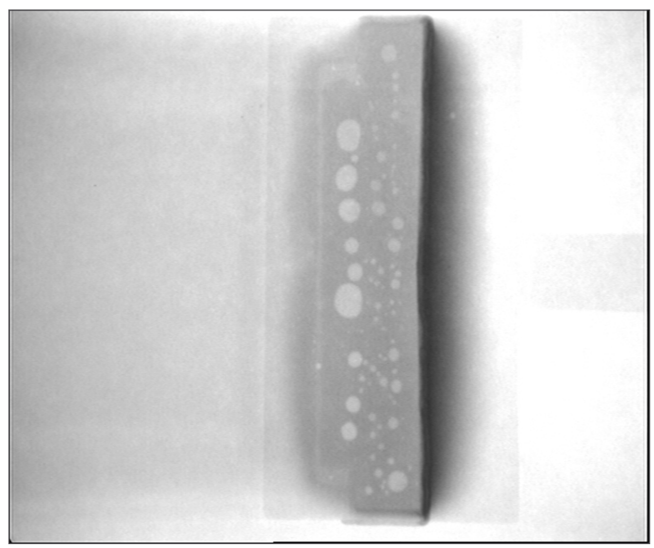


Figure 12. D3X Lead,cap,2

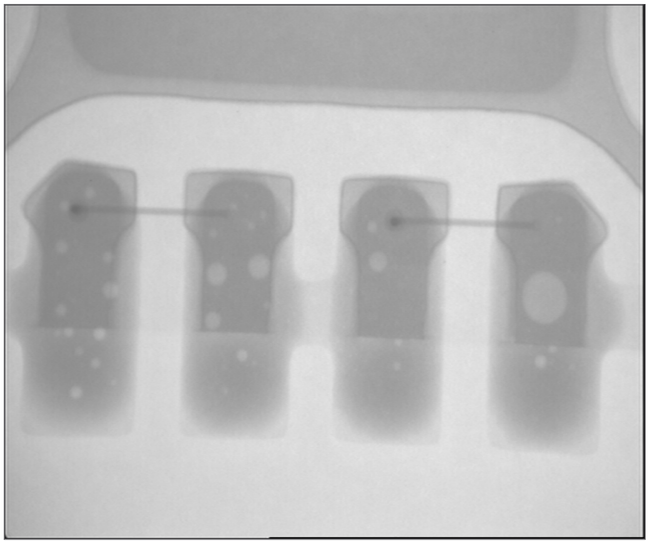


Figure 13. D3X Lead,MLFP1

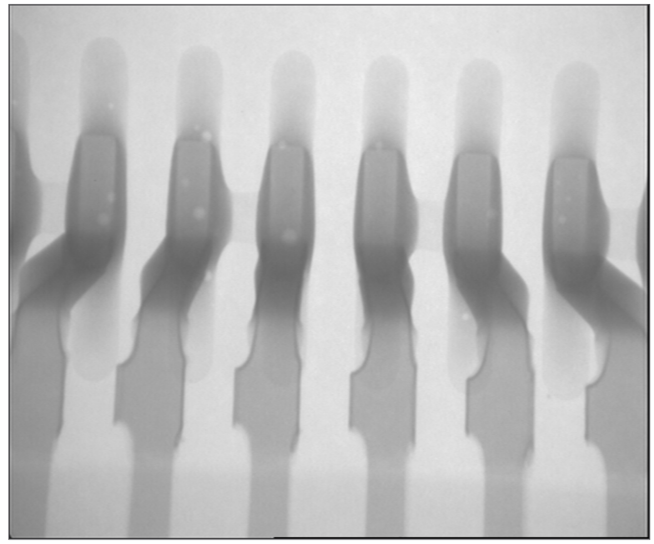


Figure 14. D3X Lead,QFP208

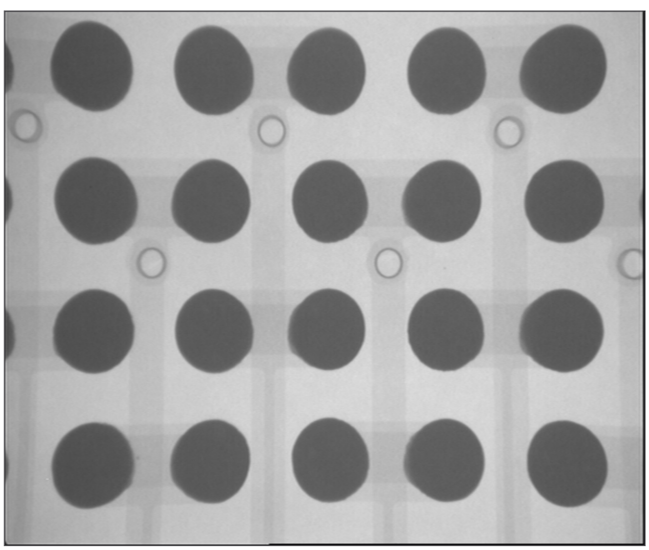


Figure 15. GX lead,70796

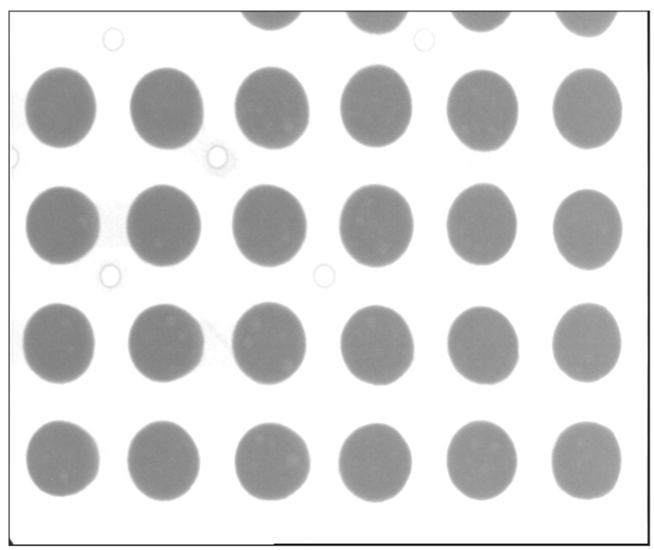


Figure 16. GX lead,71057

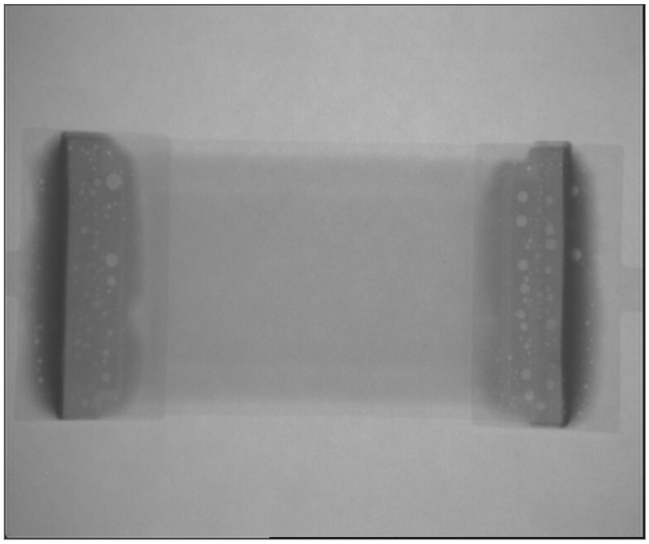


Figure 17. GX lead,cap,1

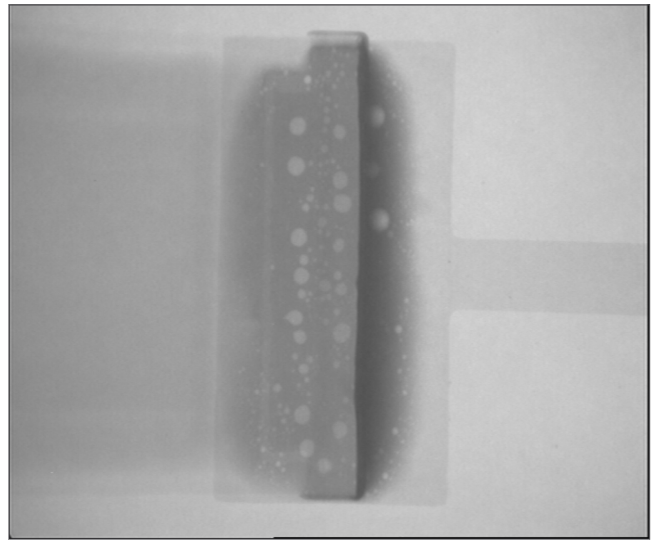


Figure 18. GX lead,cap,2

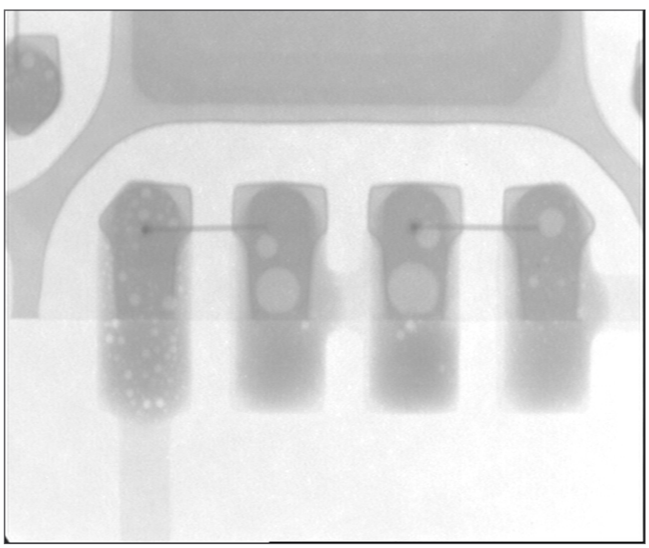


Figure 19. GX lead,MLFP1

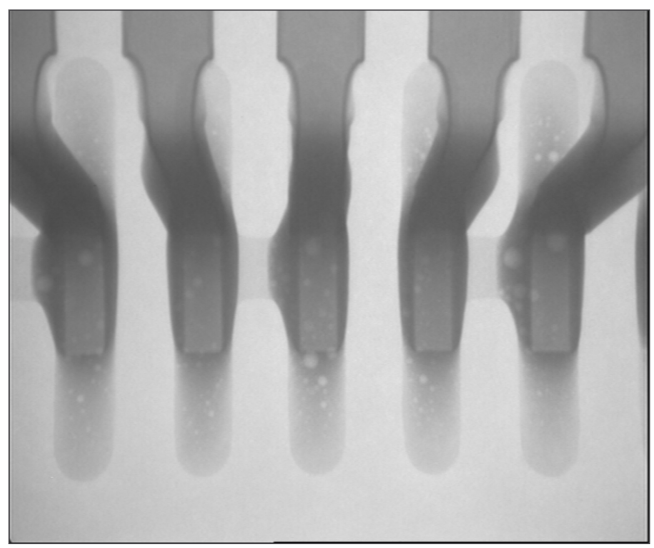


Figure 20. GX lead,QFP208,2

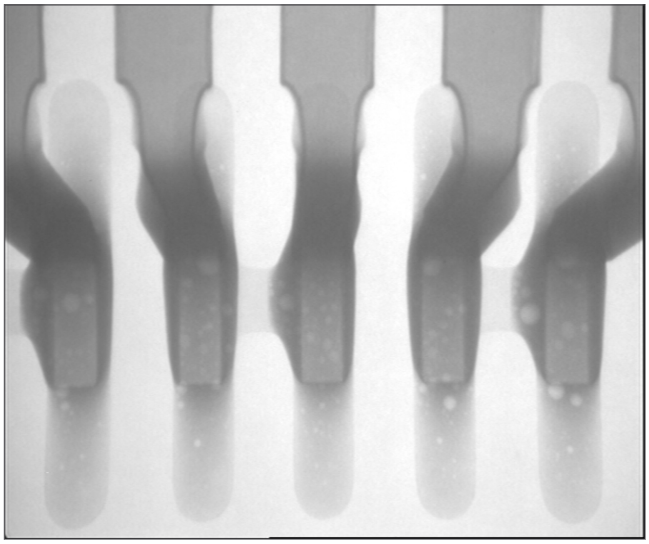


Figure 21. GX lead,QFP208

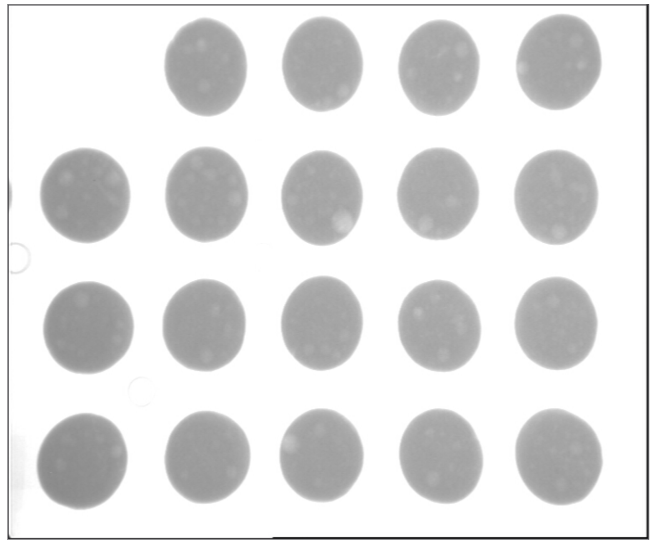


Figure 22. GX SAC,70796

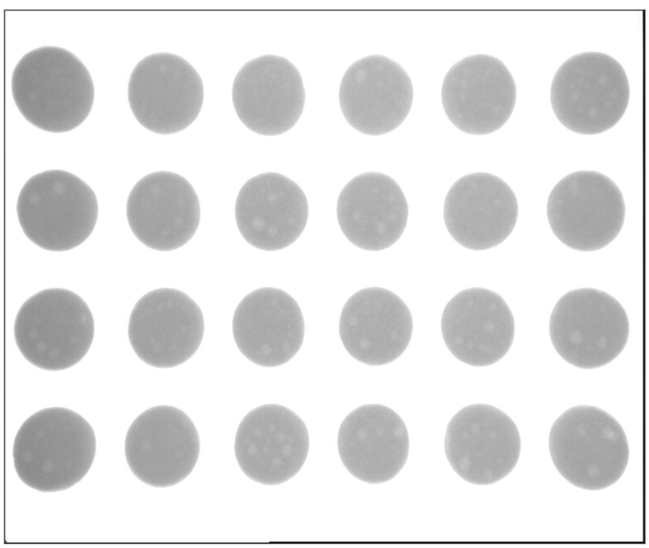


Figure 23. GX SAC,71057

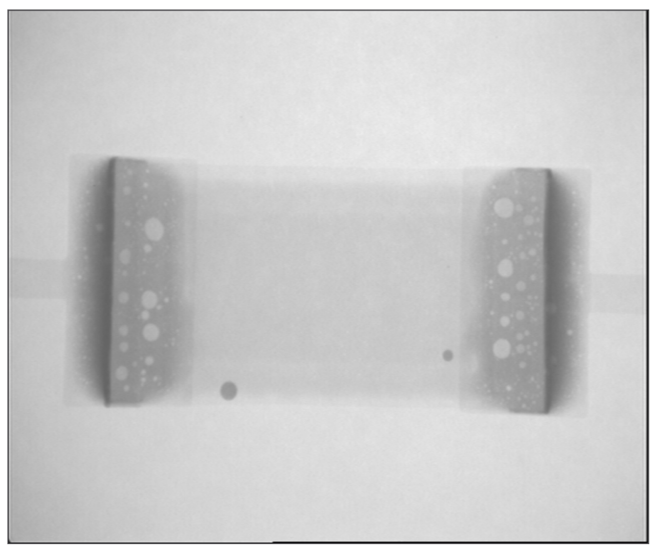


Figure 24. GX SAC,cap,1

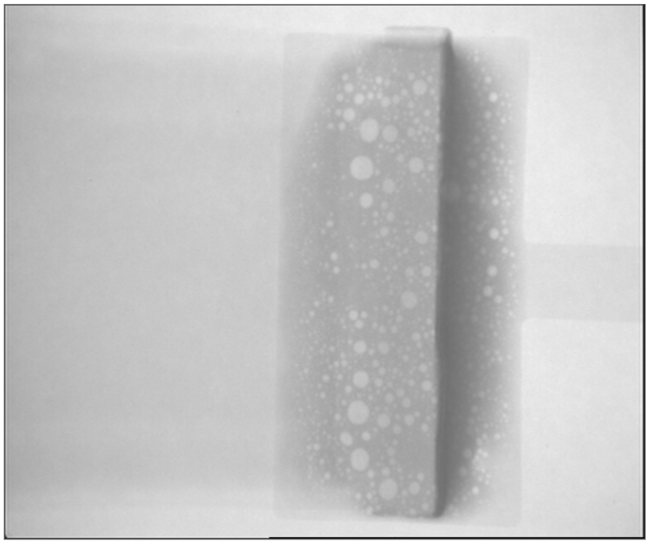


Figure 25. GX SAC,cap,2

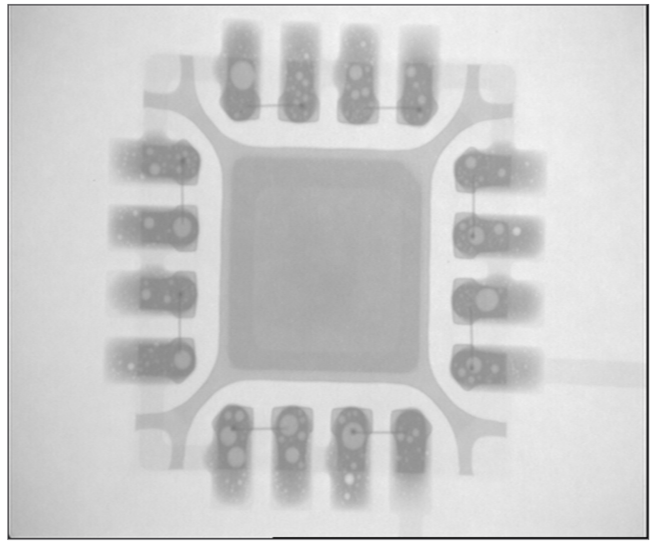


Figure 26. GX SAC,MLFP1

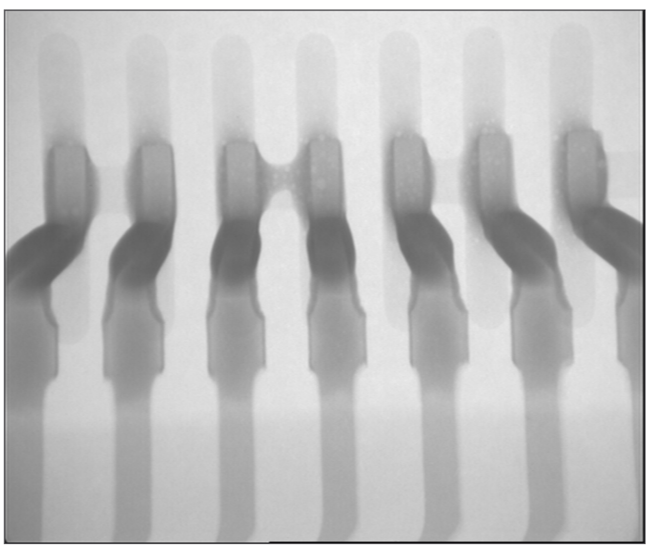


Figure 27. GX SAC,QFP208,1

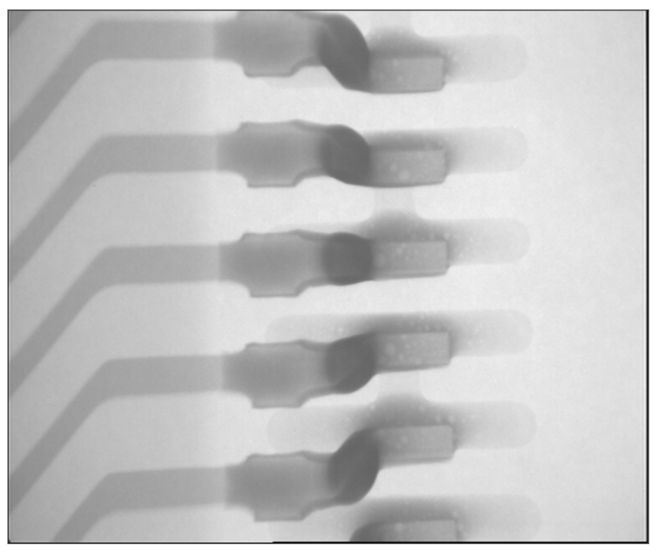


Figure 28. GX SAC,QFP208,2

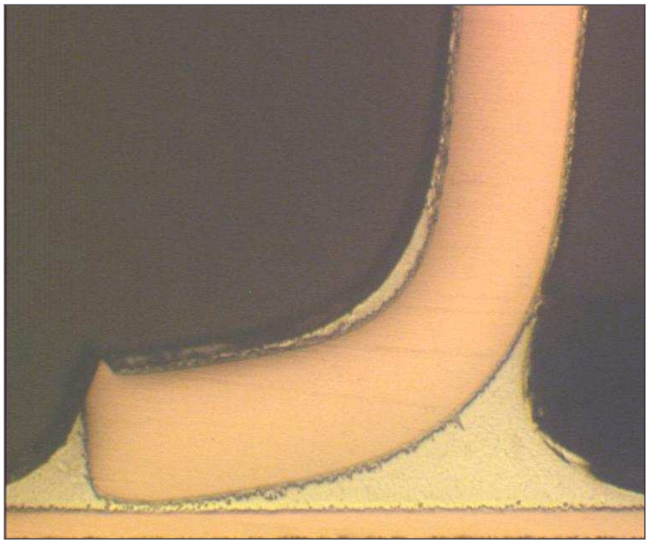


Figure 1. A3X, SAC,QFP208,100x

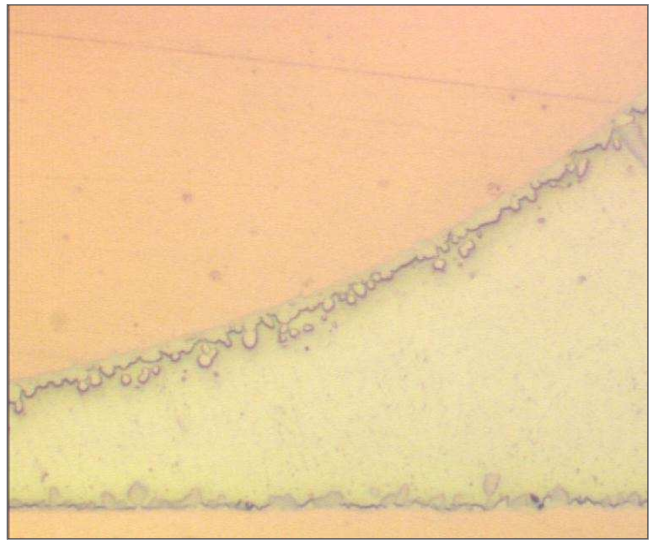


Figure 2. A3X, SAC,QFP208,400x,2

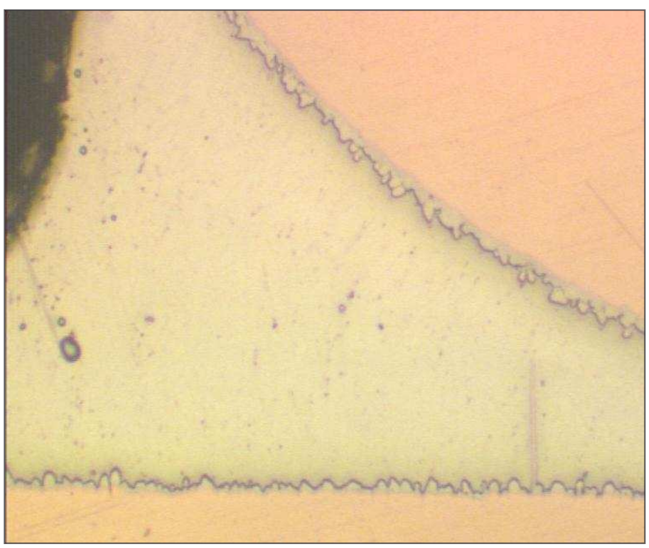


Figure 3. A3X, SAC,QFP208,400x

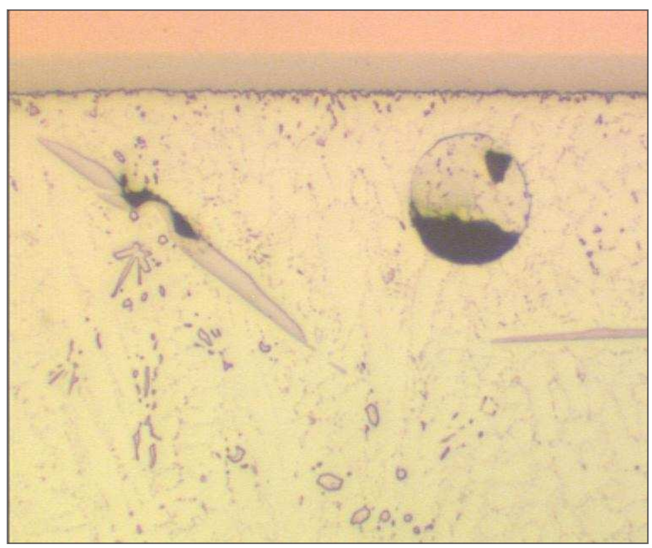


Figure 4. A3X,SAC,70796,400x,top

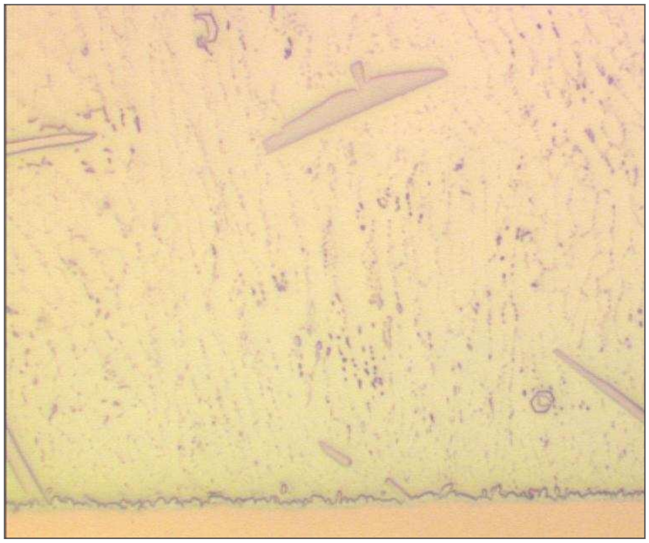


Figure 5. A3X,SAC,70796,400x

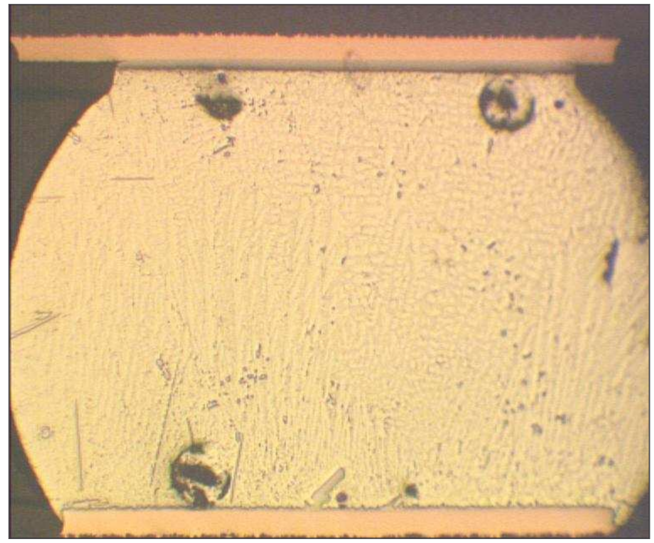


Figure 6. A3X,SAC,70796,center ball,100x,2

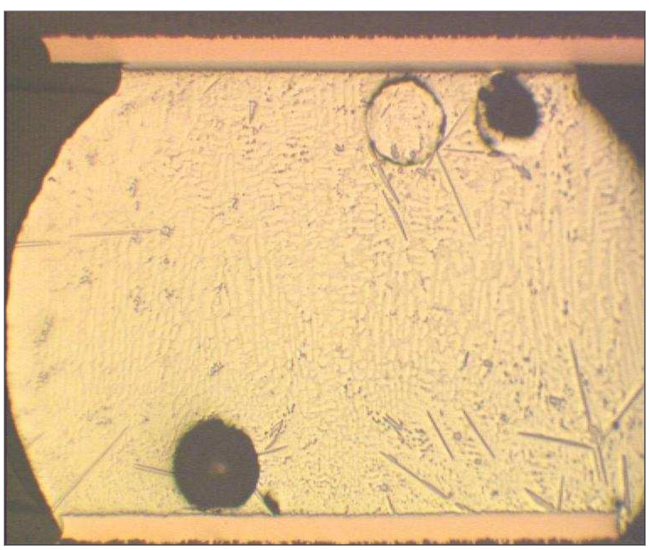


Figure 7. A3X,SAC,70796,center ball,100x

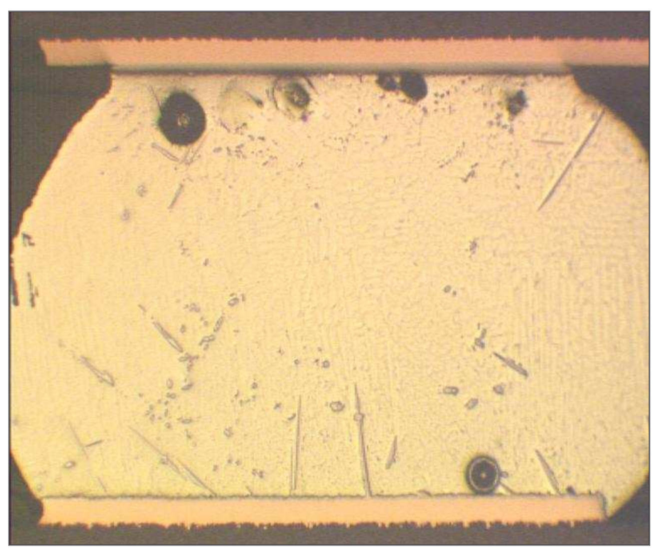


Figure 8. A3X,SAC,70796,corner ball,100x

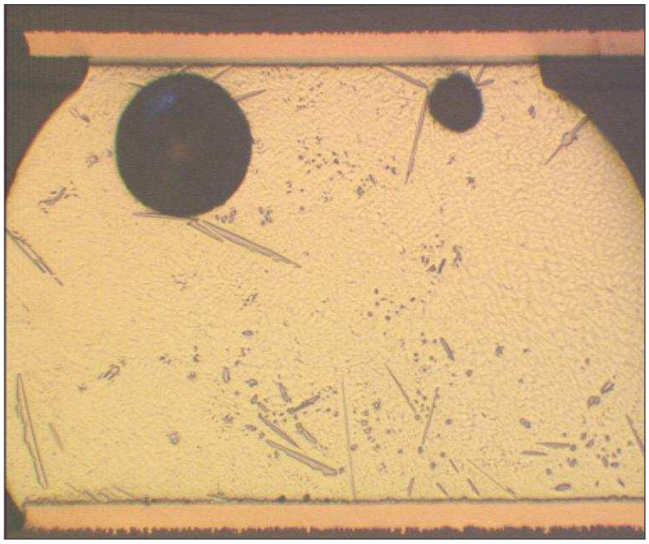


Figure 9. A3X,SAC,71057,100x,2

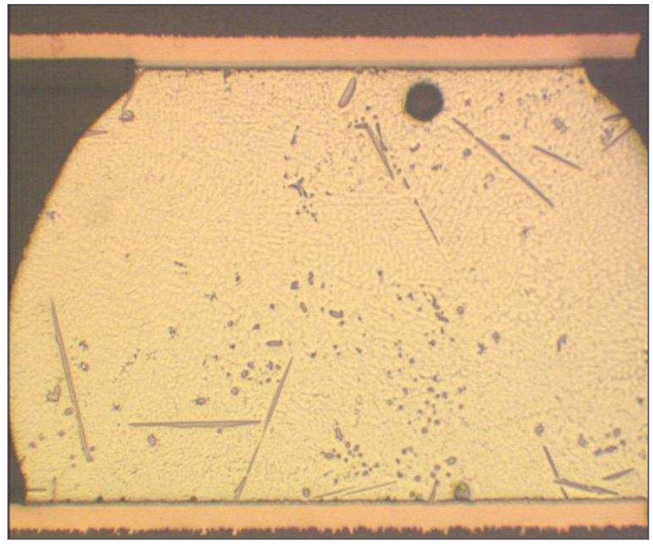


Figure 10. A3X,SAC,71057,100x

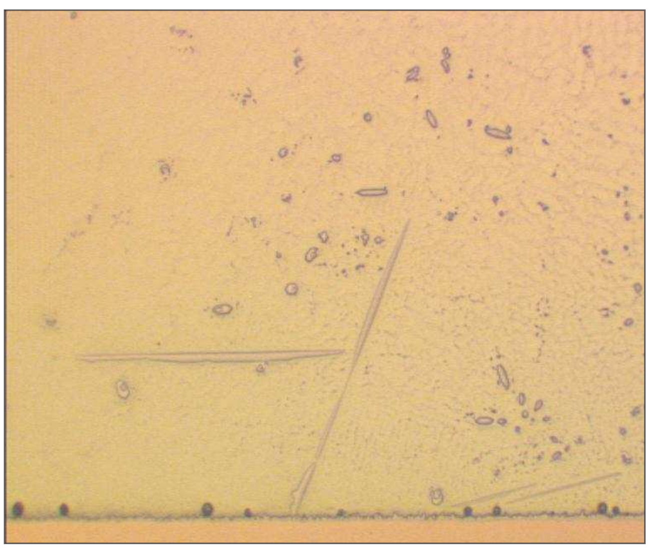


Figure 11. A3X,SAC,71057,200x

Figure 12. A3X,SAC,71057,25x,2

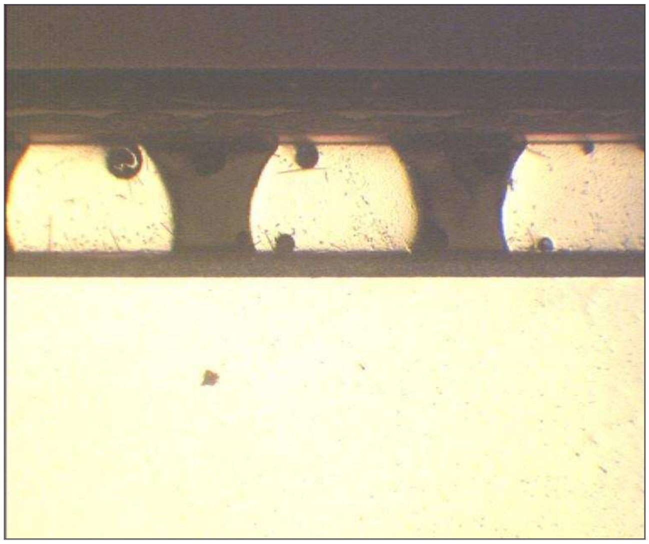
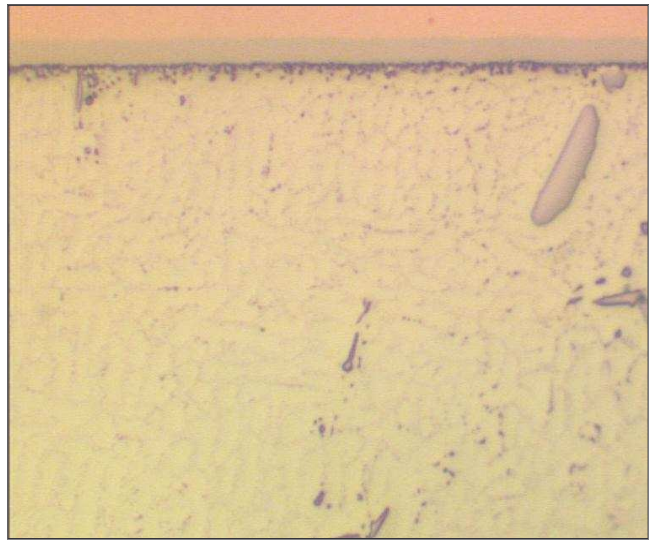


Figure 13. A3X,SAC,71057,25x



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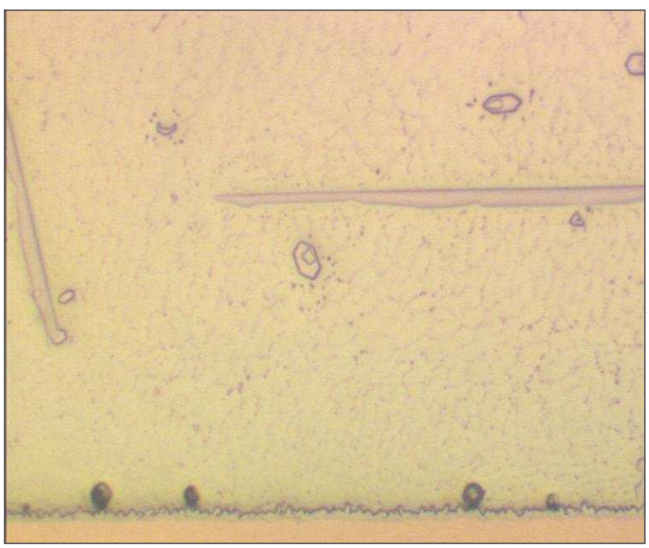
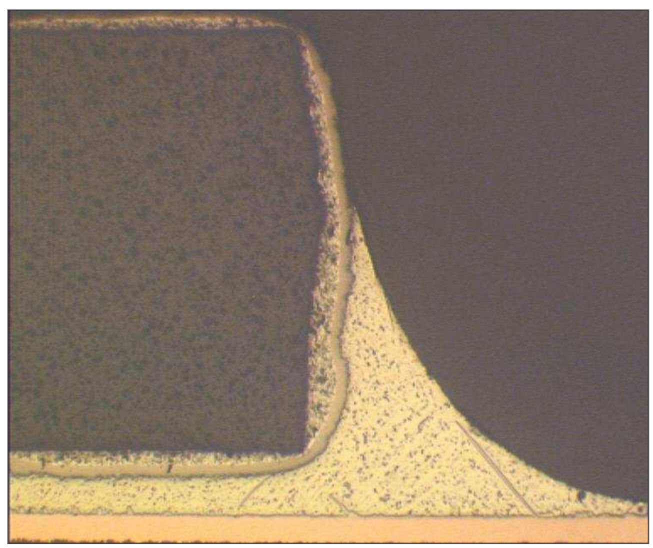


Figure 15. A3X,SAC,71057,400x



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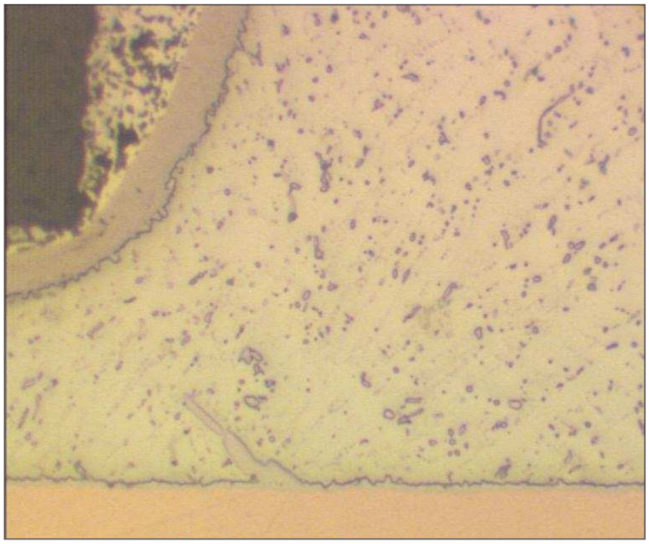

Figure 17. A3X,SAC,cap,400x

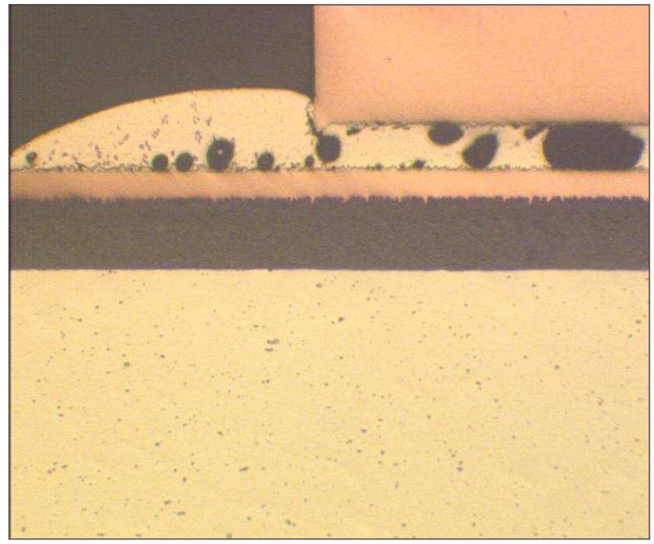

Figure 18. A3X,SAC,MLFP L16,100x,left,2

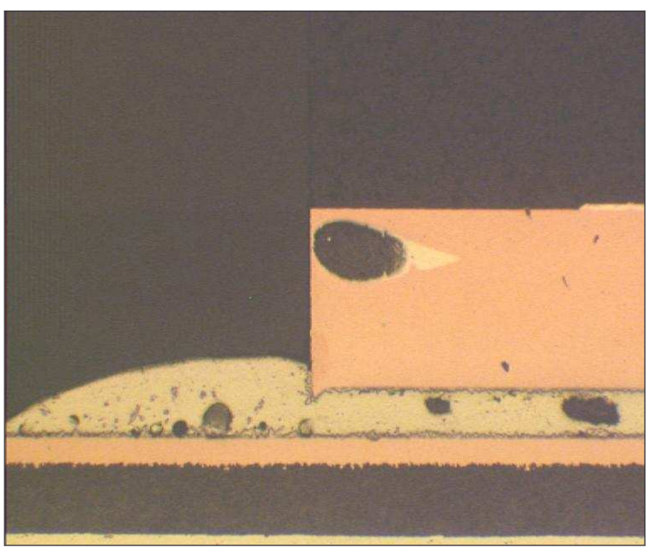

Figure 19. A3X,SAC,MLFP L16,100x,left

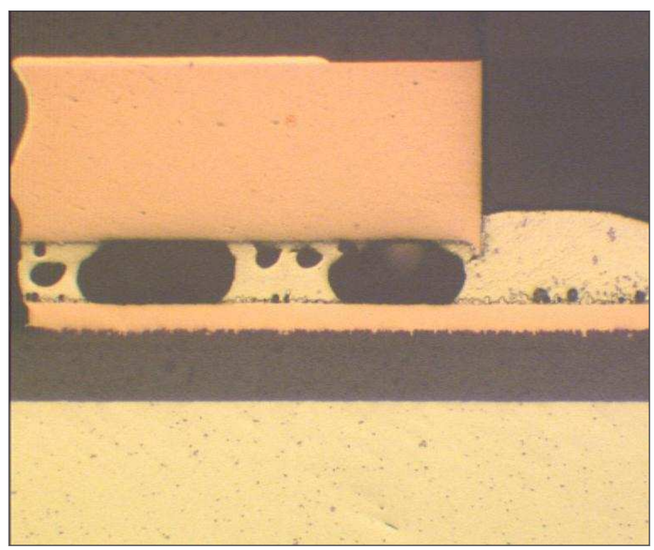

Figure 20. A3X,SAC,MLFP L16,100x,right,2

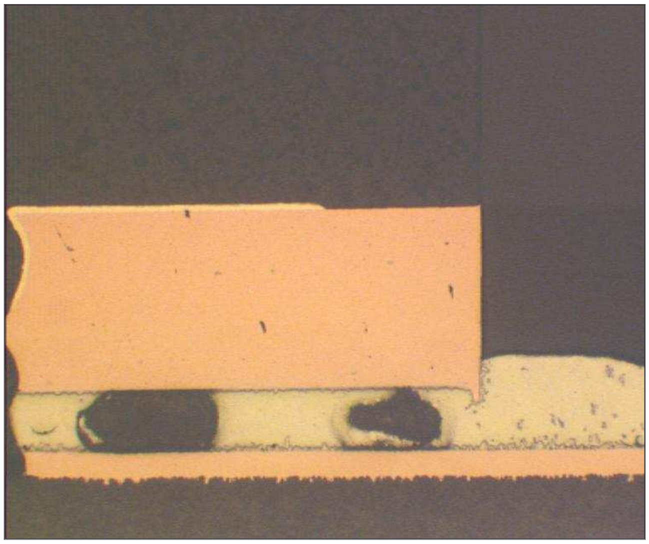

Figure 21. A3X,SAC,MLFP L16,100x,right

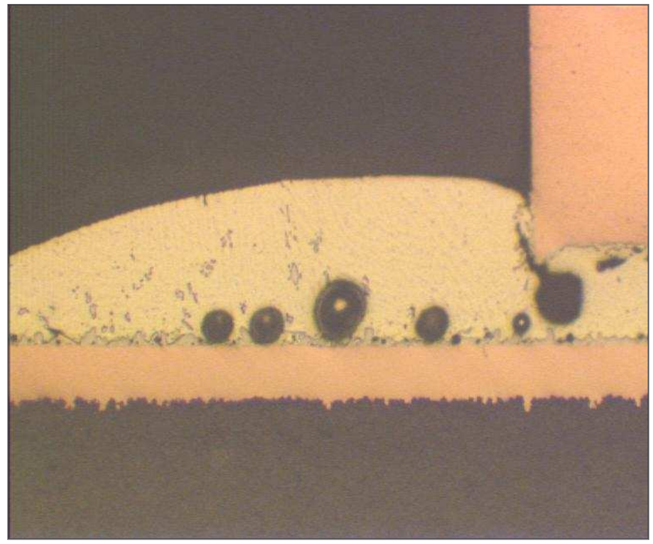

Figure 22. A3X,SAC,MLFP L16,200x,left

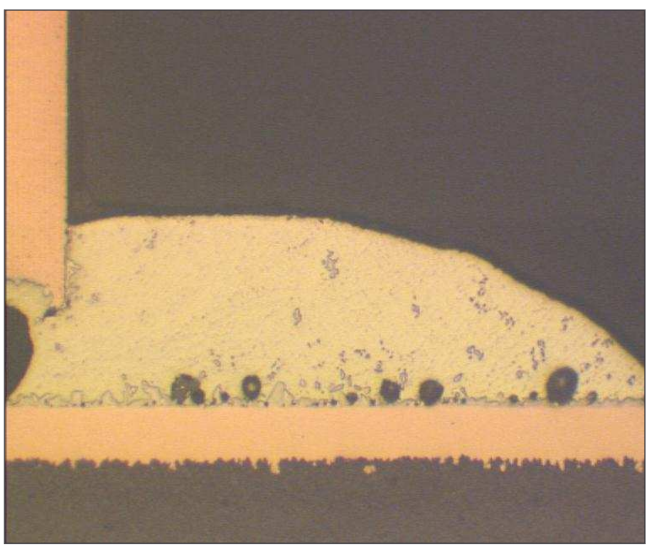

Figure 23. A3X,SAC,MLFP L16,200x,right

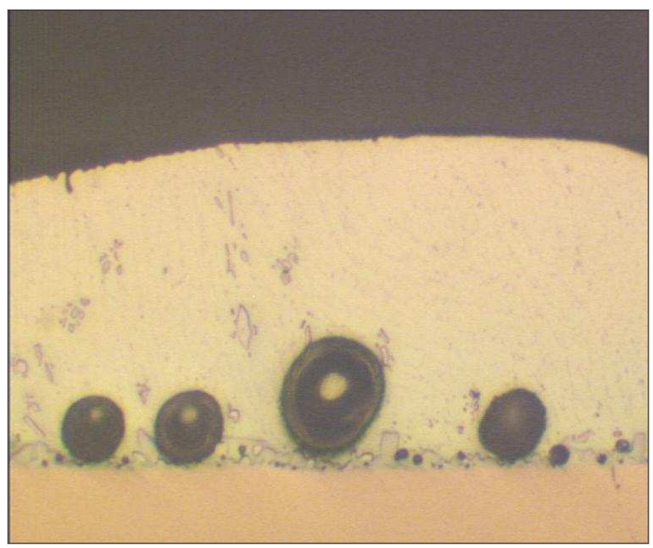

Figure 24. A3X,SAC,MLFP L16,400x,2

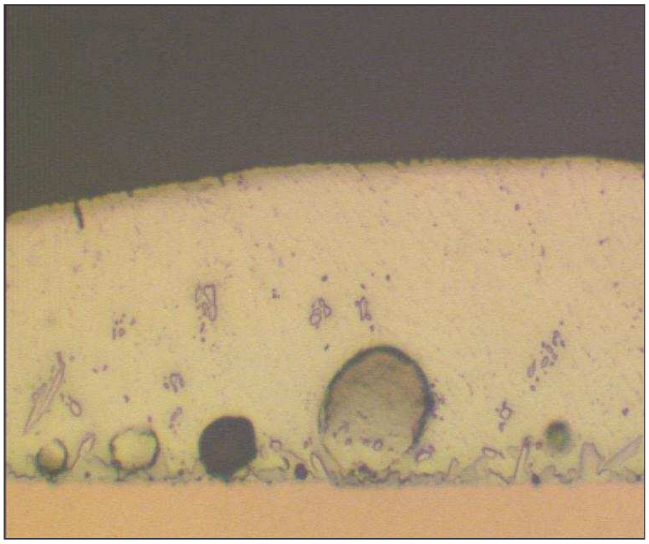

Figure 25. A3X,SAC,MLFP L16,400x

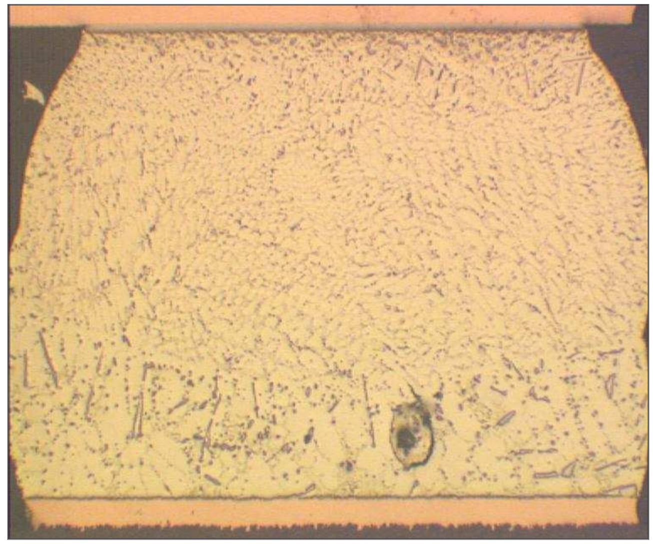

Figure 26. D3X,Pb,70796,center ball,100x,2

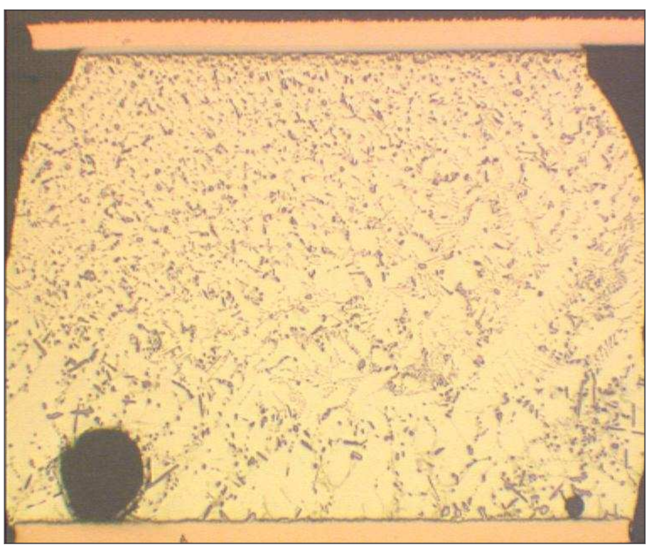

Figure 27. D3X,Pb,70796,center ball,100x

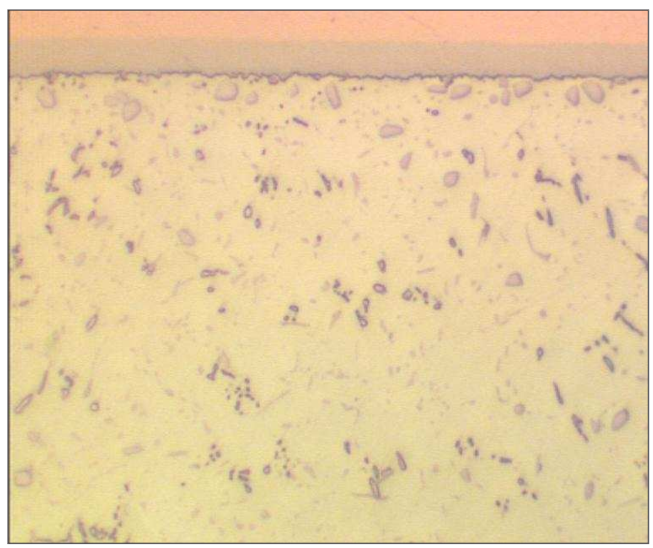

Figure 28. D3X,Pb,70796,center ball,400x,top

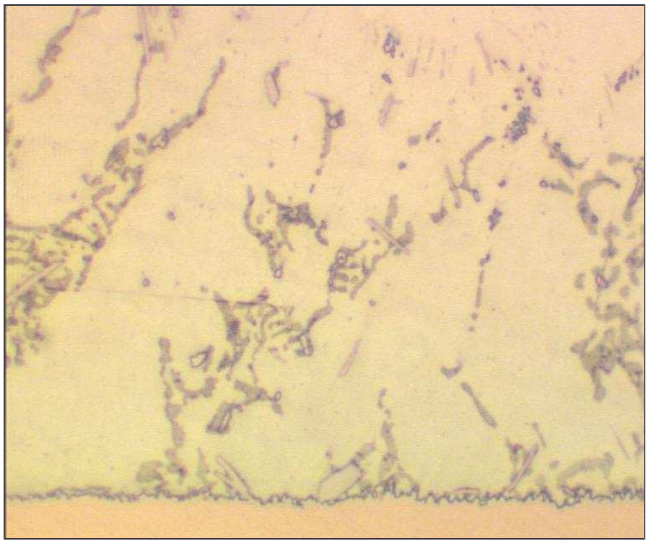

Figure 29. D3X,Pb,70796,center ball,400x

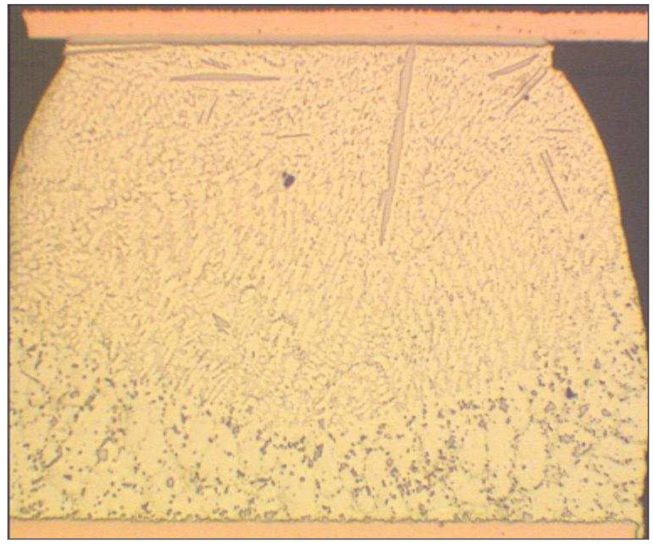

Figure 30. D3X,Pb,70796,corner ball,100x

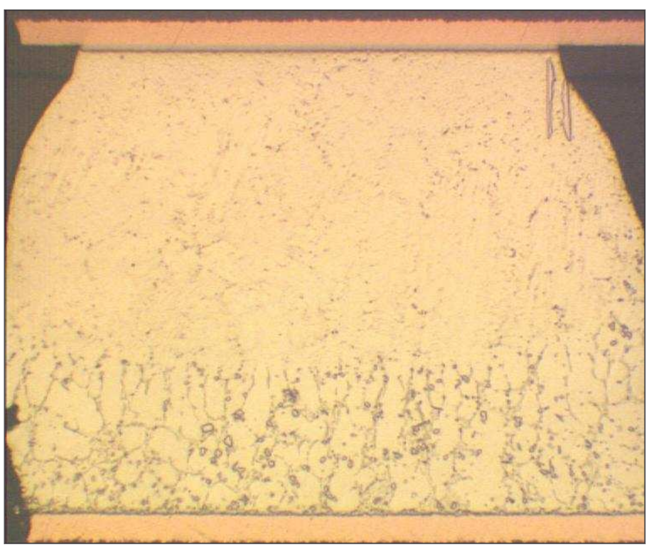

Figure 31. D3X,Pb,71057,100x

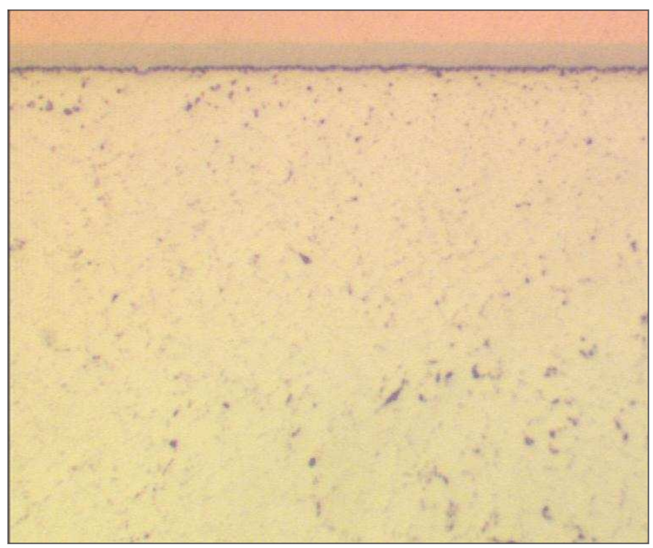

Figure 32. D3X,Pb,71057,400x,top

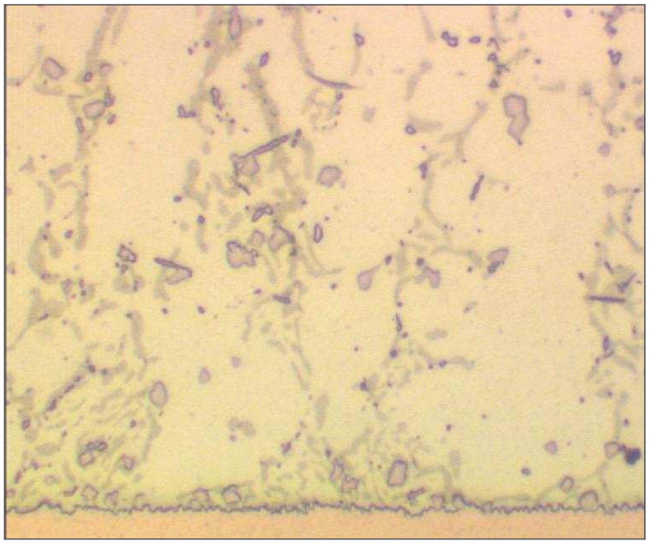

Figure 33. D3X,Pb,71057,400x

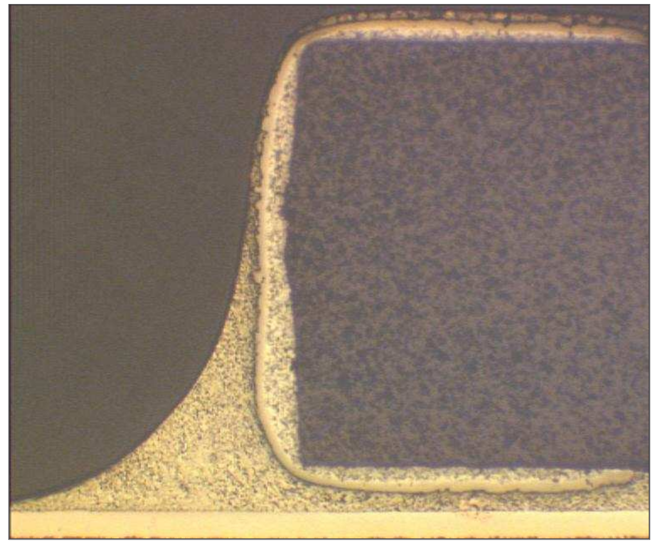

Figure 34. D3X,Pb,cap,100x

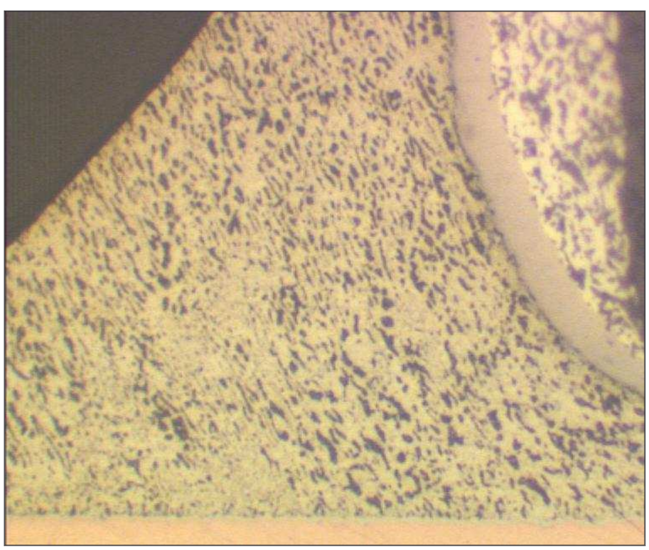

Figure 35. D3X,Pb,cap,400x

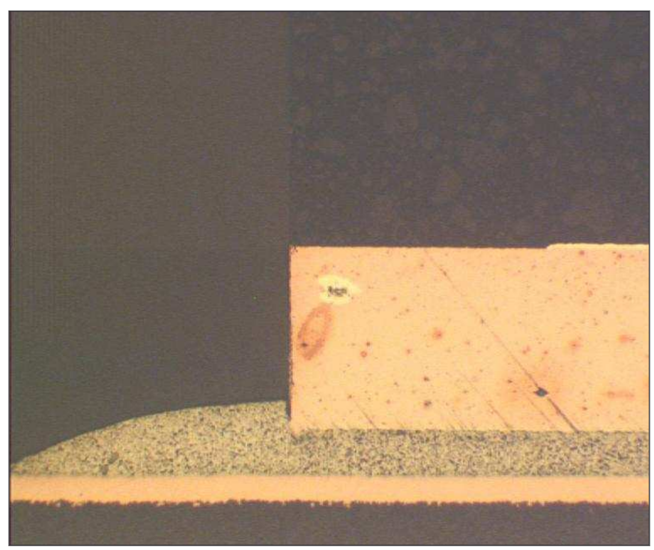

Figure 36. D3X,Pb,MLFP L16,100x,left

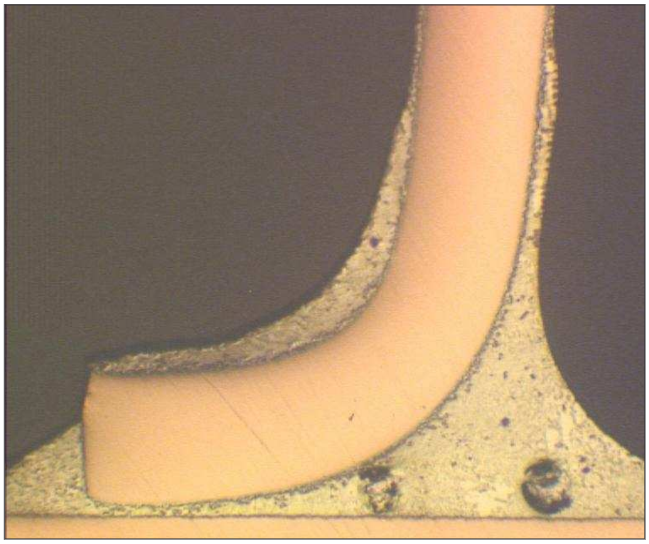

Figure 37. D3X,Pb,QFP208,100x

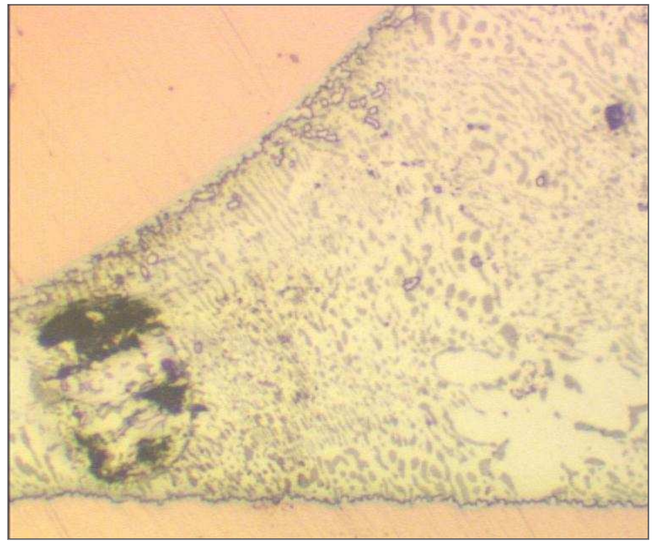

Figure 38. D3X,Pb,QFP208,400x

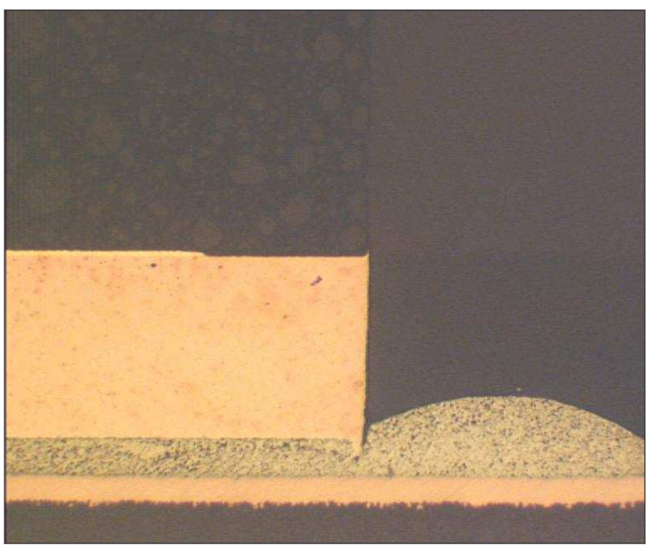

Figure 39. D3X,SAC,MLFP L16,100x,right

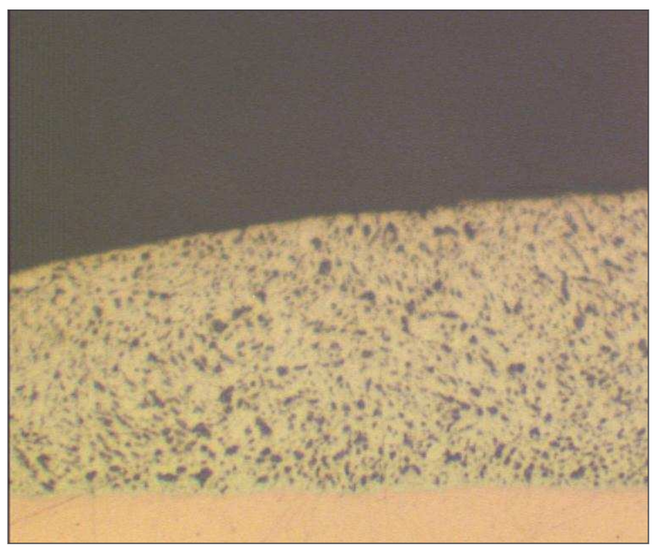

Figure 40. D3X,SAC,MLFP L16,400x

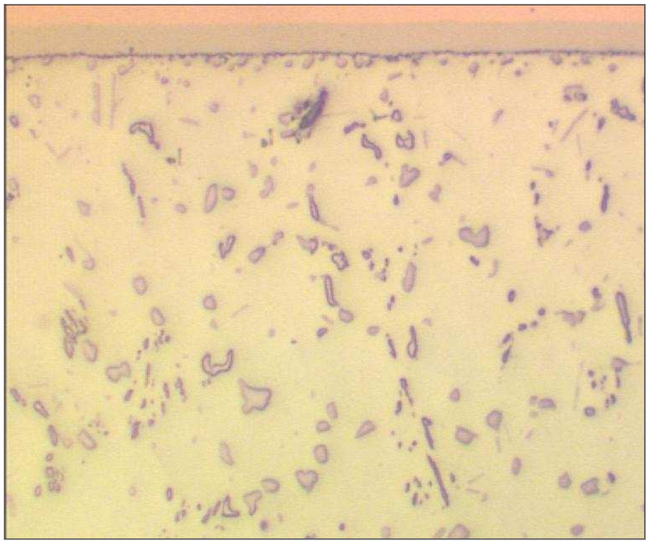

Figure 41. GX,Pb,70796,400x,top

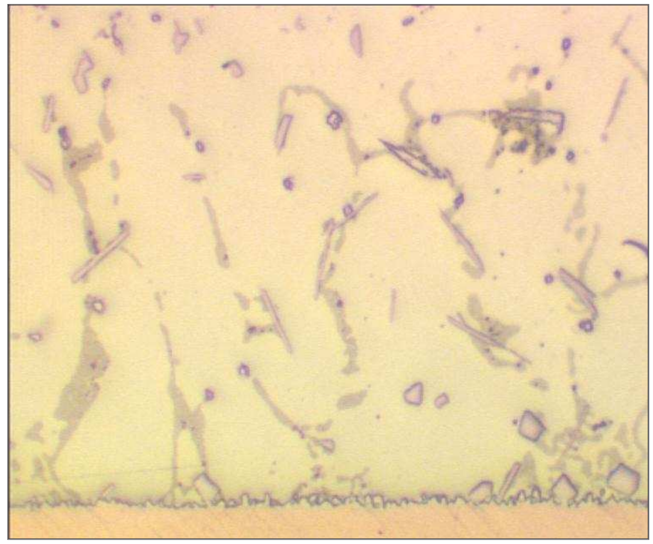

Figure 42. GX,Pb,70796,400x

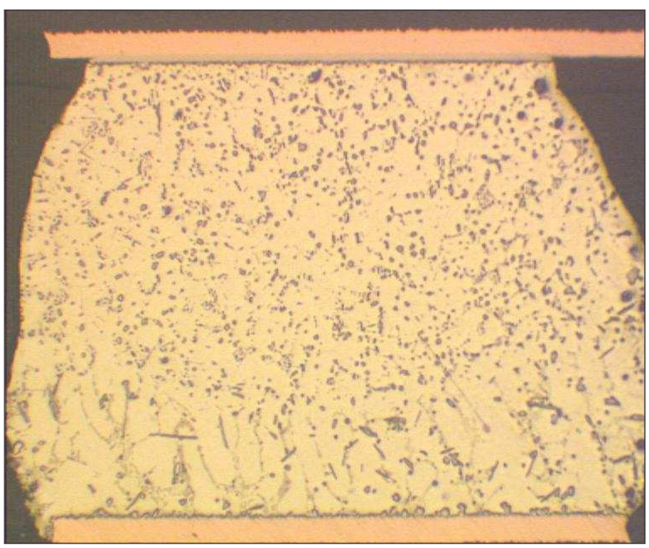

Figure 43. GX,Pb,70796,center ball,100x

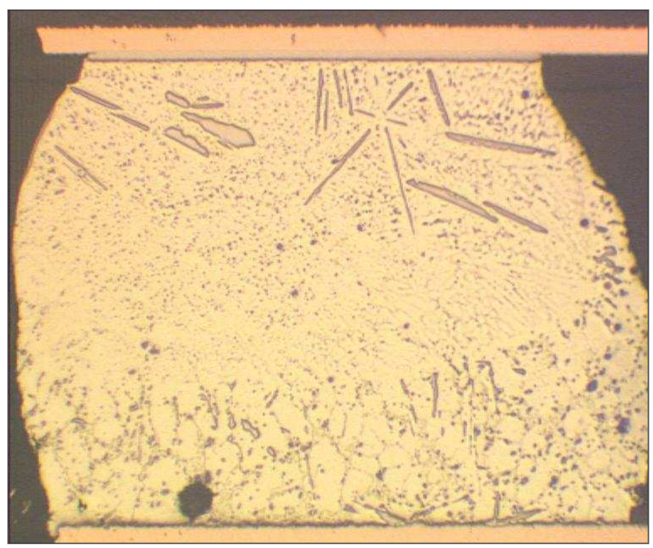

Figure 44. GX,Pb,70796,corner ball,100x

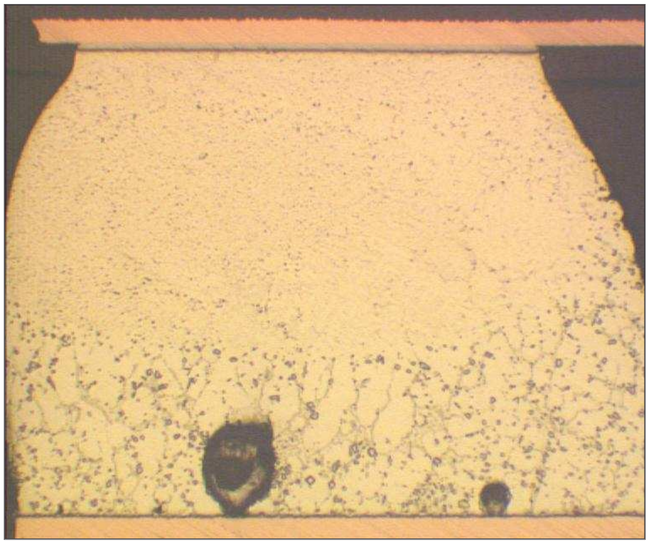

Figure 45. GX,Pb,71057,100x,2

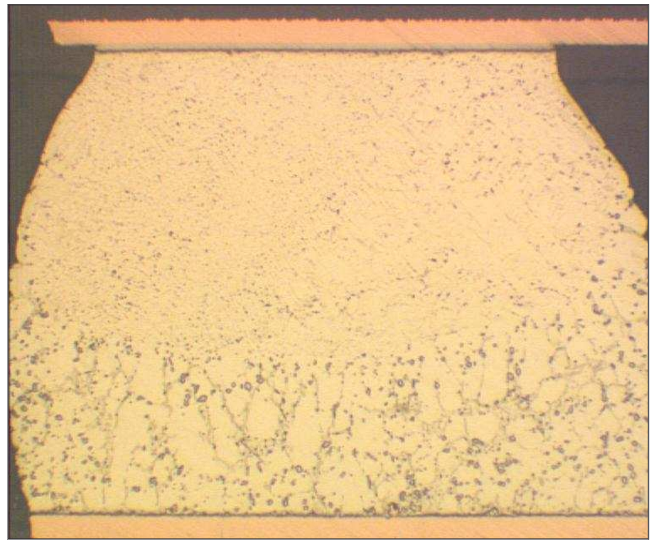

Figure 46. GX,Pb,71057,100x

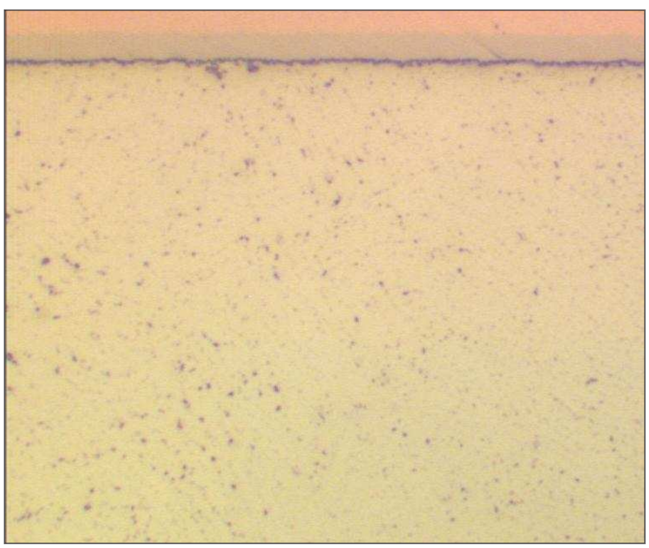

Figure 47. GX,Pb,71057,400x,top

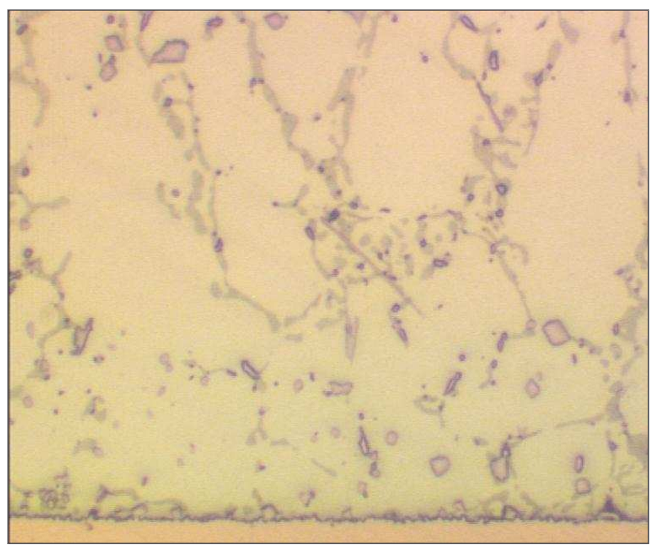

Figure 48. GX,Pb,71057,400x

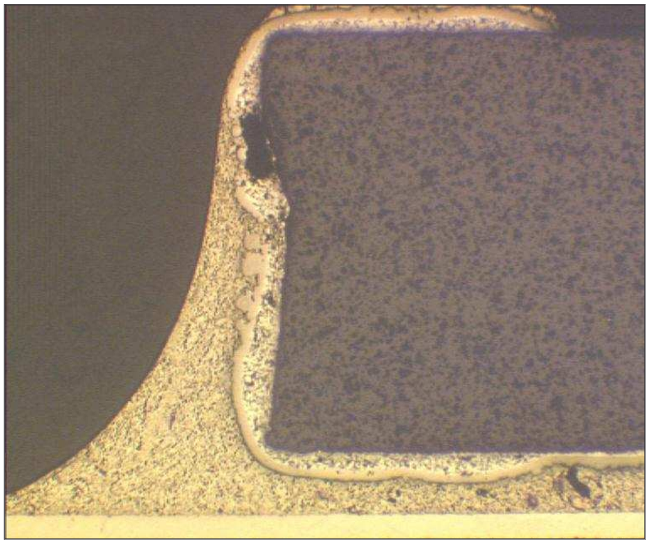

Figure 49. GX,Pb,cap,100x

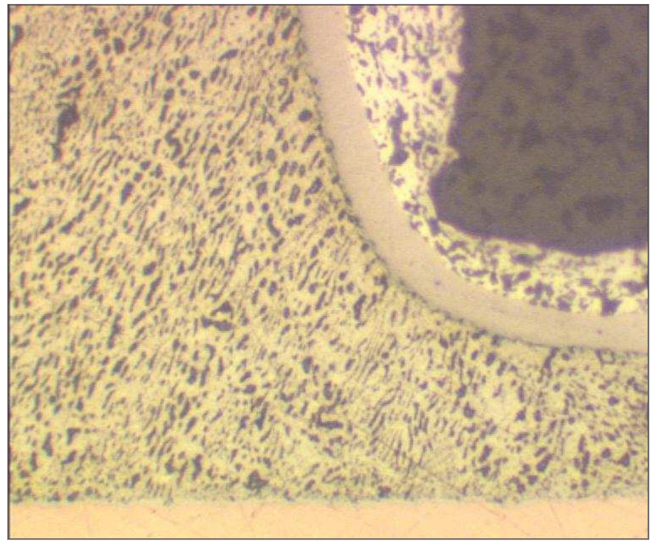

Figure 50. GX,Pb,cap,400x

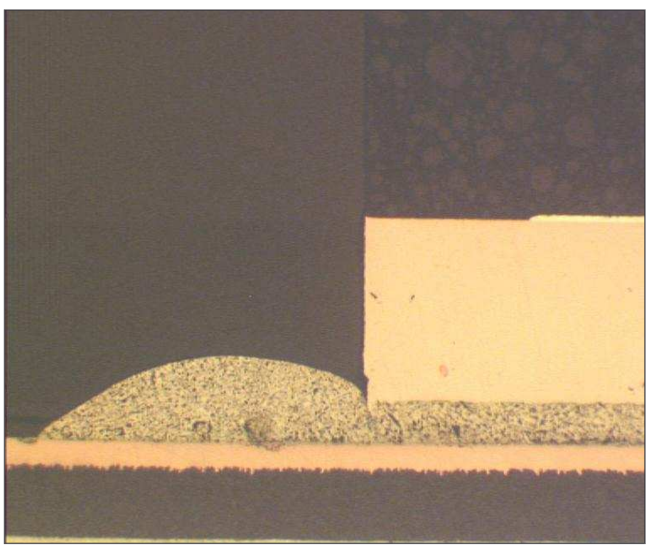

Figure 51. GX,Pb,MLFP L16,100x,left

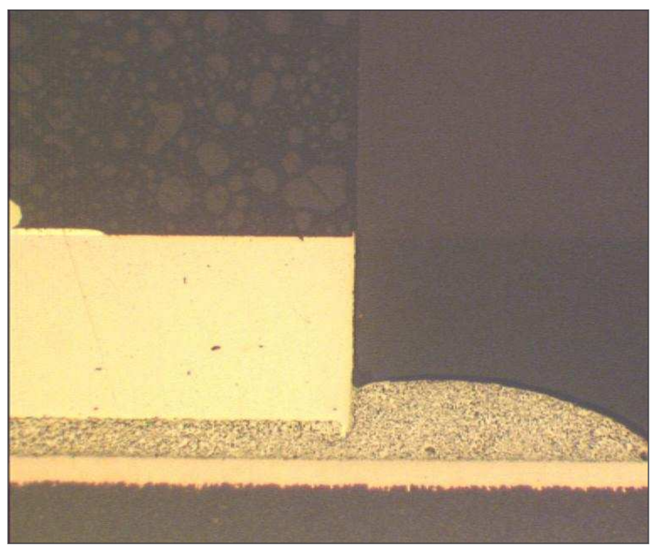

Figure 52. GX,Pb,MLFP L16,100x,right

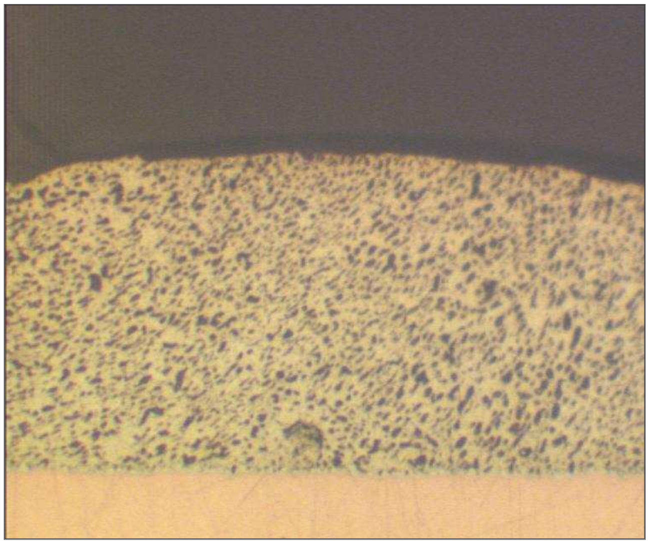

Figure 53. GX,Pb,MLFP L16,400x,right

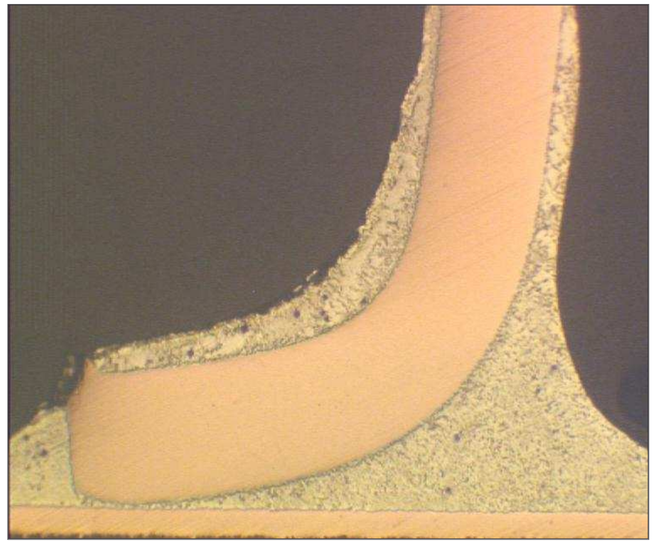

Figure 54. GX,Pb,QFP208,100x

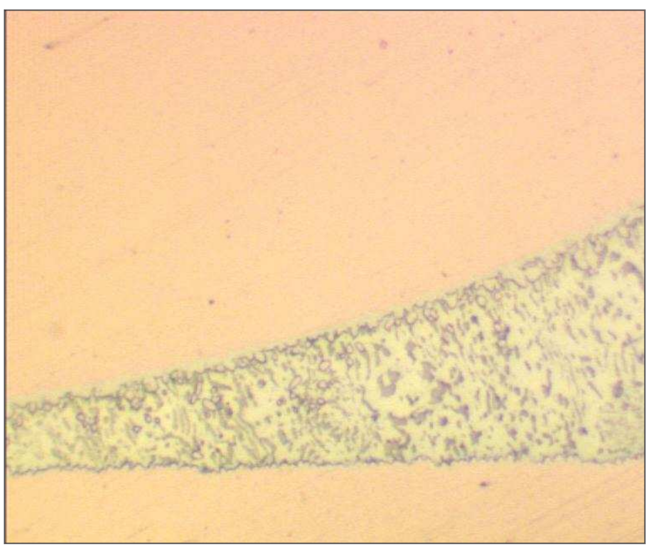

Figure 55. GX,Pb,QFP208,400x

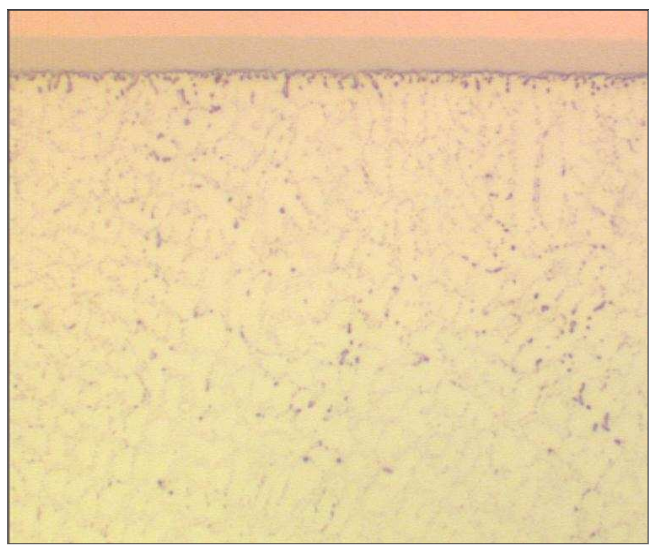

Figure 56. GX,SAC,70796,400x,top

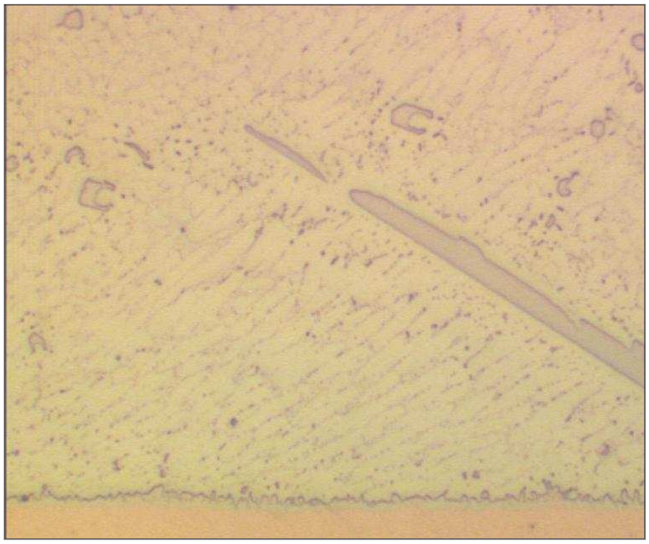

Figure 57. GX,SAC,70796,400x

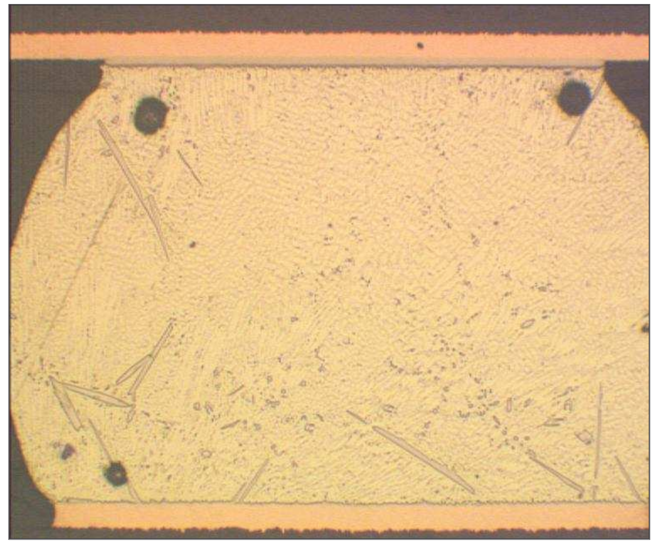

Figure 58. GX,SAC,70796,center ball,100x

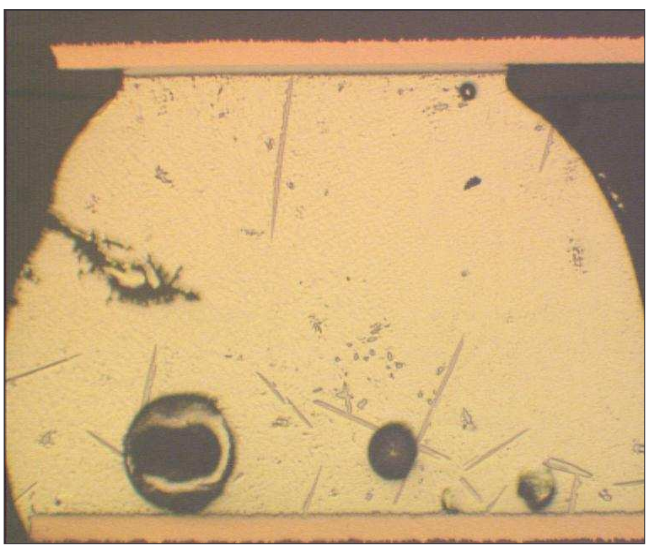

Figure 59. GX,SAC,70796,corner ball,100x

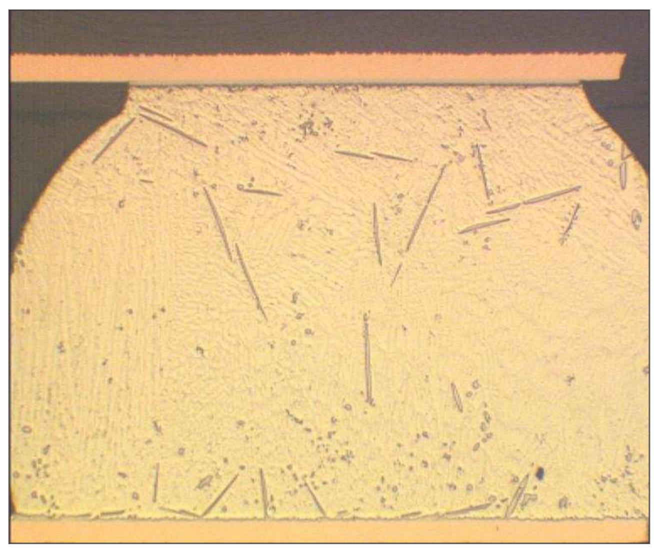

Figure 60. GX,SAC,71057,100x,2

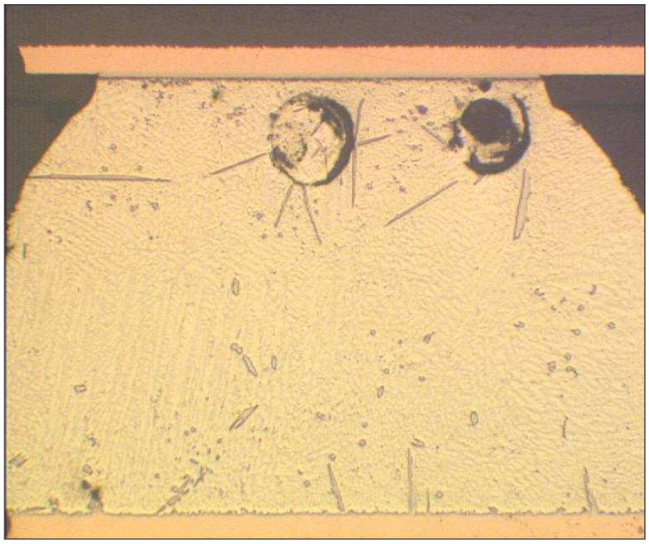

Figure 61. GX,SAC,71057,100x

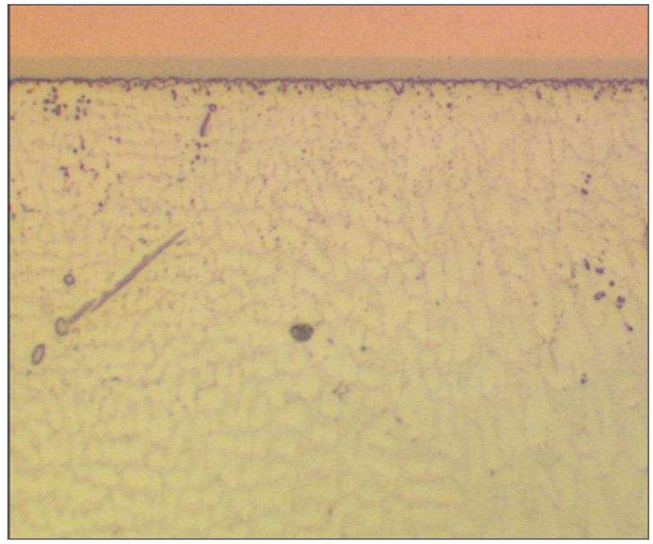

Figure 62. GX,SAC,71057,400x,top

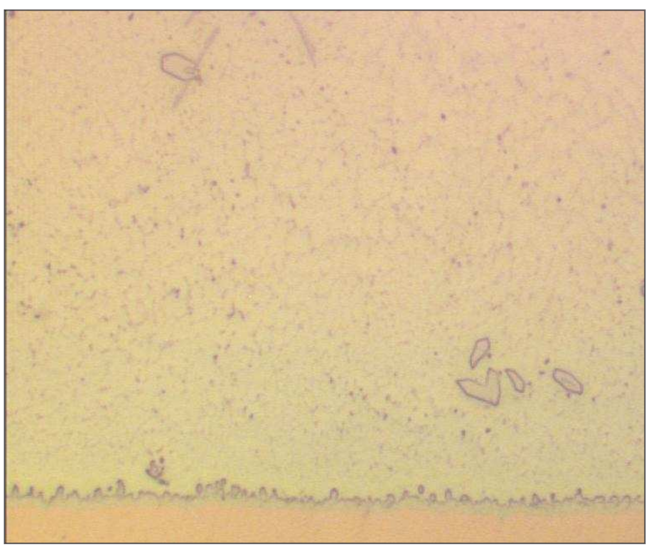

Figure 63. GX,SAC,71057,400x

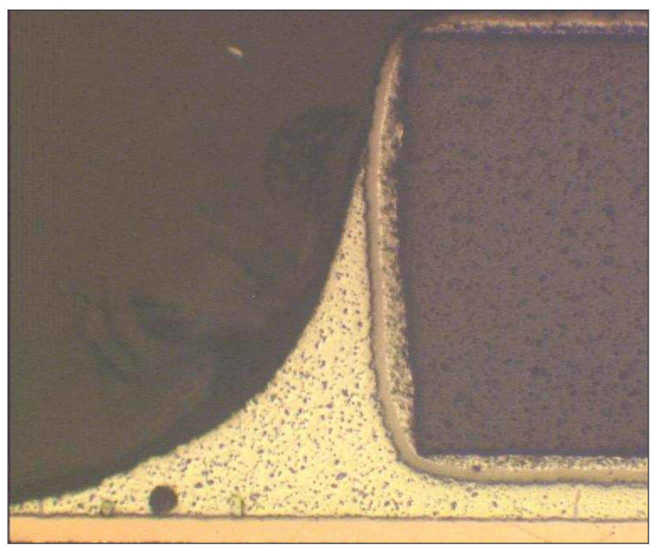

Figure 64. GX,SAC,cap,100x

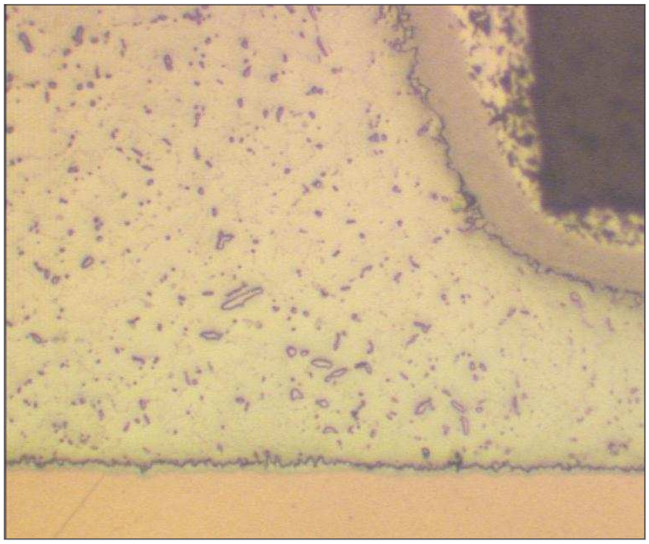
Figure 65. GX,SAC,cap,400x

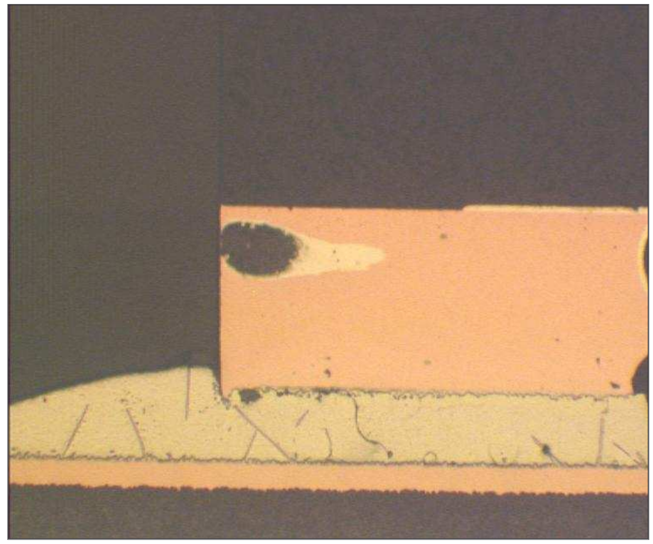
Figure 66. GX,SAC,MLFP L16,100x,left

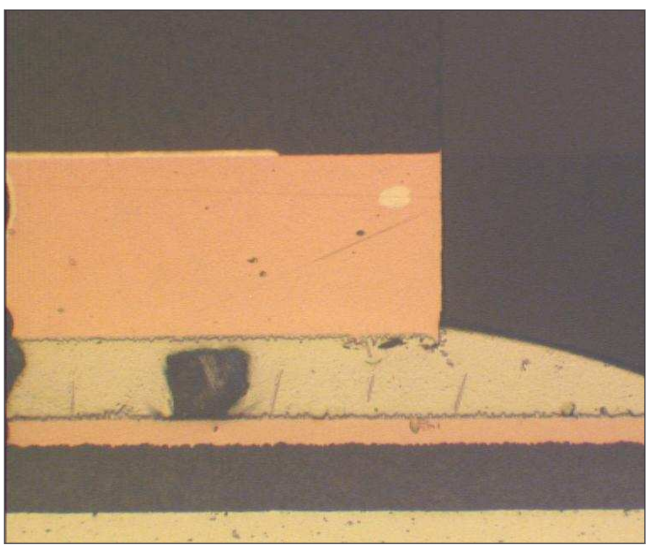
Figure 67. GX,SAC,MLFP L16,100x,right

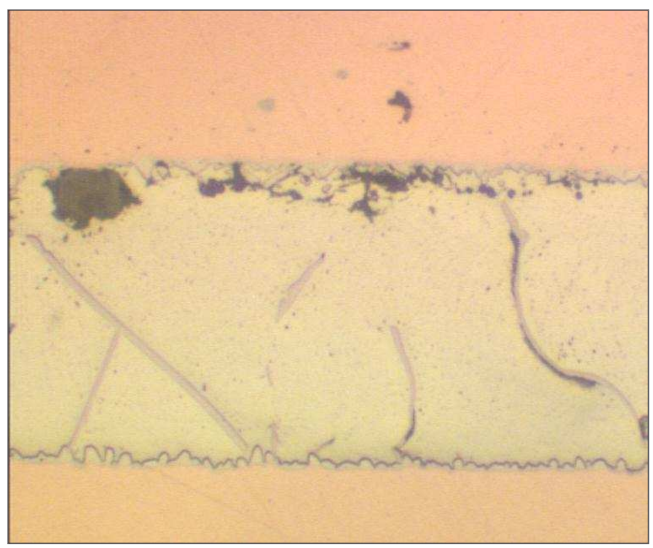
Figure 68. GX,SAC,MLFP L16,400x,left

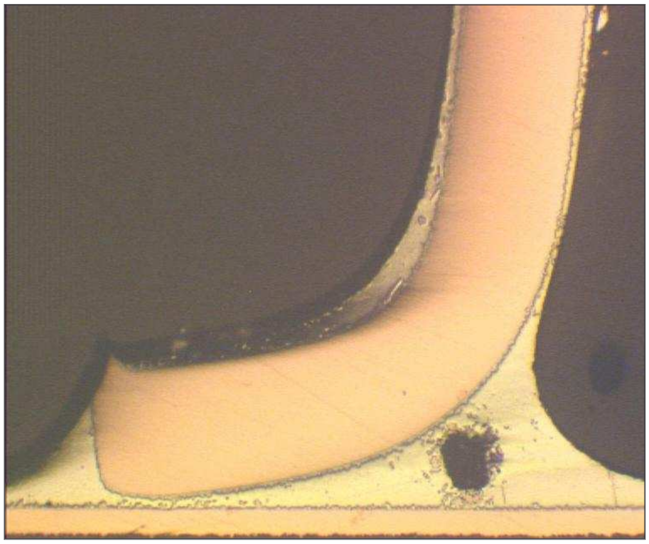

Figure 69. GX,SAC,QFP208,100x

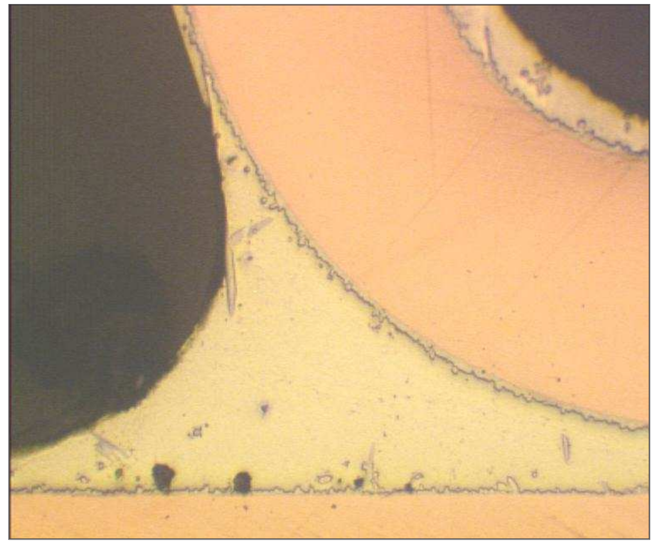

Figure 70. GX,SAC,QFP208,200x

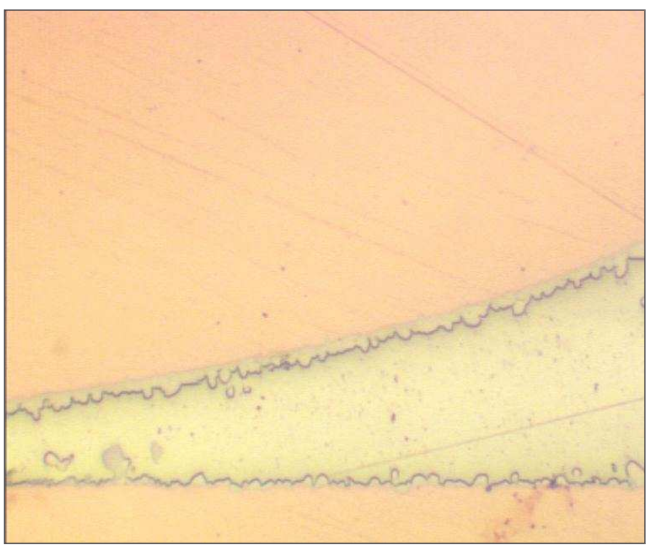

Figure 71. GX,SAC,QFP208,400x

Solder Joint Integrity Impact of Immersion Silver Surface Finish Thickness for Tin/Lead and Lead-free Solder Processes

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Rockwell Collins Inc
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ABSTRACT

An Institute of Printed Circuits (IPC) Plating Processes subcommittee 4-14 test program was undertaken to assess how printed wiring board immersion silver plating thickness impacts solder joint integrity. The study compared typical immersion silver plating thicknesses against extreme immersion plating thicknesses for a set of standard electronic component types used on printed circuit boards. The investigation test results demonstrated that the immersion silver printed wiring board surface finish thickness in both a tin/lead and a lead-free soldering process did impact the solder joint integrity for a -55ºC to +125ºC thermal cycle temperature range. A recommendation was made to review the current IPC-4553 maximum immersion silver plating thickness value and consider implementing a maximum immersion silver surface thickness in the 15-30 micro-inch range.

BACKGROUND

The Institute of Printed Circuits (IPC) Plating Processes subcommittee 4-14 develops guidelines, test methods and techniques for evaluating process control parameters on electrolytic and electroless/immersion plating systems. The Plating Processes committee had developed the IPC-4553 Immersion Silver Plating for Printed Circuit Boards specification which sets the requirements for the use of immersion silver as a surface finish for printed circuit boards. During the development phase of this specification, an investigation was undertaken to understand how immersion silver plating thickness impacts solder joint integrity. The activity focused on a comparing typical immersion silver plating thicknesses to extreme immersion plating thicknesses for a set of standard electronic component types used on printed circuit boards.

OBJECTIVE

The objective of this investigation was to determine the impact of immersion silver printed wiring board surface finish thickness used in either a tin/lead or a lead-free soldering process on solder joint integrity for a -55ºC to +125ºC thermal cycle temperature range.

PROCEDURES

Test Vehicle

Figure 1 illustrates the test vehicle used in the IPC committee investigation. The test vehicle was designed to meet IPC-6012, Class 3, Type 3 requirements. The test vehicle laminate selected for the testing program was Bergquist T-Clad, an epoxy/6061 aluminum metal clad configuration. The test vehicle construction was designed to create significant coefficient of thermal expansion (CTE) mismatch stresses on the solder joints. An immersion silver finish was applied by each surface chemistry supplier in a “standard” thickness “X” that met the requirements of the IPC-4553 specification and an “excess” thickness that significantly exceeded the requirements of the IPC-4553 specification by a factor of approximately three times the standard thickness, i.e. “3X”. A set of test vehicles, finished with an Organic Solderability Preservative (OSP) were included in the investigation as a solder joint integrity baseline.

Table 1 illustrates the test vehicle vendors and the supplied immersion silver finish thicknesses as measured by X-ray Fluorescence (XRF) spectroscopy.

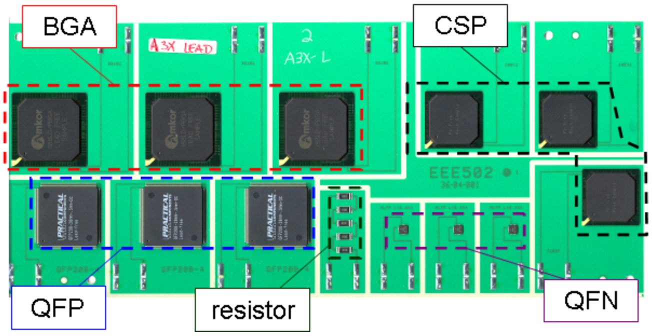

Figure 1 Representative Test Vehicle

Component Type	"A" std	"A" 3X	"F" std	"F" 3X	"G" std	"G" 3X
QFP	15.43	45.92	11.00	30.86	19.99	60.55
QFP	15.28	33.97	11.90	26.88	16.97	48.85
2512	5.49	34.56	8.25	32.34	5.30	41.83
2512	6.02	41.38	7.32	31.29	5.79	21.77
QFN	7.52	43.15	14.28	32.87	11.11	59.41
QFN	11.20	48.68	11.88	30.45	15.86	60.25
QFN	11.76	53.15	12.85	31.47	20.42	53.88
BGA	6.47	37.09	9.79	34.02	18.37	61.00
BGA	5.25	37.31	10.07	36.24	22.03	65.87
BGA	5.38	49.08	10.76	34.94	23.21	69.74

Table 1 Test Vehicle Plating Thickness (in micro inches) Note: Immersion silver thickness data not provided for suppliers “D” and “E”. CSP data not provided for all suppliers.

Test Components
Five component types were included in the investigation. These component types were selected to represent a basic solder joint integrity situation (e.g. the surface mount resistor) and a complex solder joint integrity case (e.g. the ball grid array components). The components are identified in Figure 1.

Test Vehicle Assembly
Test vehicle assembly was assembled with both Sn63Pb37 alloy solderpaste and SAC305 alloy solderpaste at a Celestica printed wiring assembly facility [1]. The test vehicles were then shipped to Rockwell Collins for thermal cycle testing.

Thermal Cycle Parameters and Methodology
The temperature cycle range used in the investigation was -55ºC to +125ºC with a 10 minute dwell at both the high temperature and the low temperature extremes. A maximum temperature ramp of 10°C/minute was used in the testing. The components were continuously monitored throughout thermal cycle testing with an event detector in accordance with the IPC-9701 specification, with each component treated as a single resistance channel. An ‘event’ was recorded if the resistance of a channel exceeded 300 Ω for more than 0.2 μsec. A failure was defined when a component either:

- Recorded an event for 15 consecutive cycles,
- Had five consecutive detection events within 10% of current life of test, or
- Became electrically open.

Once a solder joint was designated a failure, the event detection system software excluded it from the remainder of the test. Detailed temperature profiling was conducted prior to the beginning of the thermal cycle conditioning to ensure that each test vehicle was subjected to uniform, consistent exposure to the test chamber temperatures. Figure 2 illustrates the measured test vehicle temperatures.

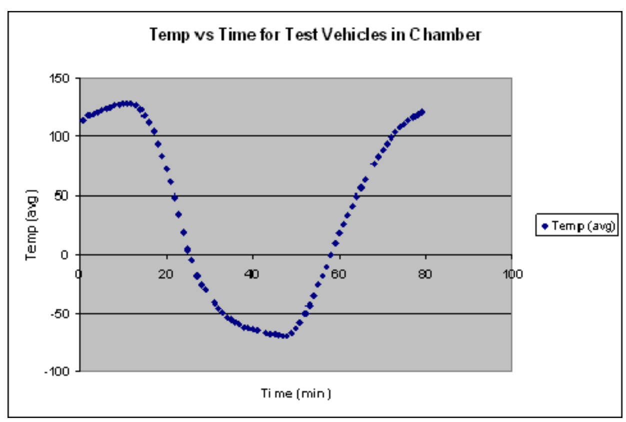

Figure 2 Thermal Cycle Profile for the -55ºC to +125ºC Testing

TEST RESULTS: DATA ANALYSIS
The test vehicles were subjected to a total of 2000 thermal cycles before testing was stopped. At this point, all of the BGA, Resistor, CSP, and QFN parts had failed, but all of the QFP components were still functional. In the majority of cases, only three samples were included in the

testing for any combination of part style, solderpaste and surface finish. The exceptions were the resistors, which generally had only a single sample for each combination, and some combinations with SAC solderpaste that had six samples in the test. Due to the small sample sizes in this study a failure distribution analysis, such as determining the Weibull parameters, was not attempted.

Instead, the failure data were analyzed to determine the average cycles to failure and the corresponding standard deviations. Figure 3 presents the results of the average number of thermal cycles to failure for component and solderpaste combinations for each surface finish tested. As all BGA, resistor, CSP, and QFN components in this study eventually did fail, a missing combination (such as BGAs with SnPb3X solderpaste and the 'D' surface finish) indicates that no samples with this combination were tested. Error bars show the range of ± 1 standard deviation of the average cycles to failure. Resistor combinations that had only one sample do not have error bar. Given the dearth of test data for resistors, it is difficult to draw any statistically significant conclusions from the results shown in Figure 3.

It does appear that the components with SAC solderpaste fairly consistently survived more thermal cycles than those with SnPb. The results do not clearly indicate any significant effect of surface finish on resistor reliability, but again with the small sample size this is more of an observation than a conclusion. There did not seem to be any strong, consistent differences between average fatigue lives of the SnPb and SAC solderpaste combinations (except as noted previously in the small sample size results for Resistors) and the effect of finish thickness (X vs. 3X) was similarly negligible. On the area array components (BGA's and CSP's), surface finishes D, E and OSP were generally associated with higher average lifetimes than F, G or (to a smaller extent) A.

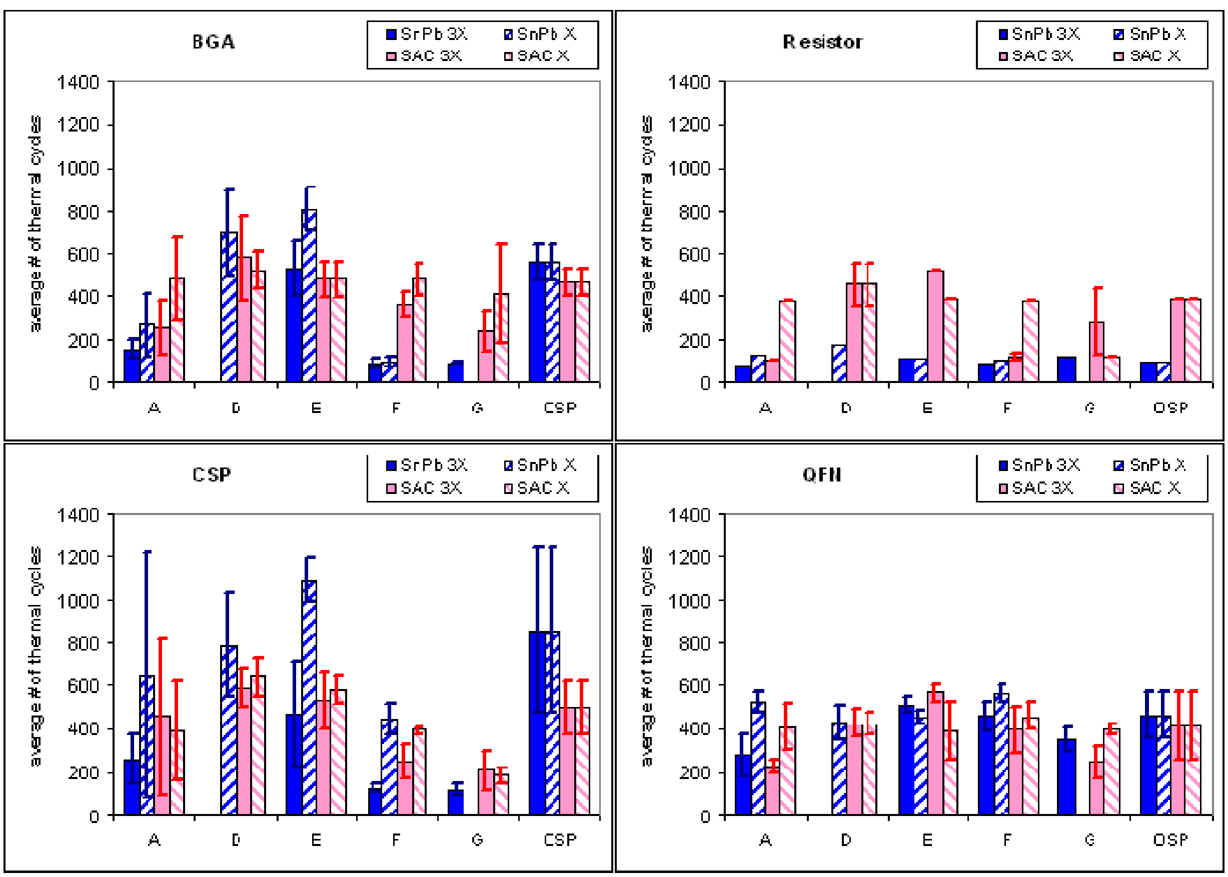

Figure 3 Average Cycles to Failure

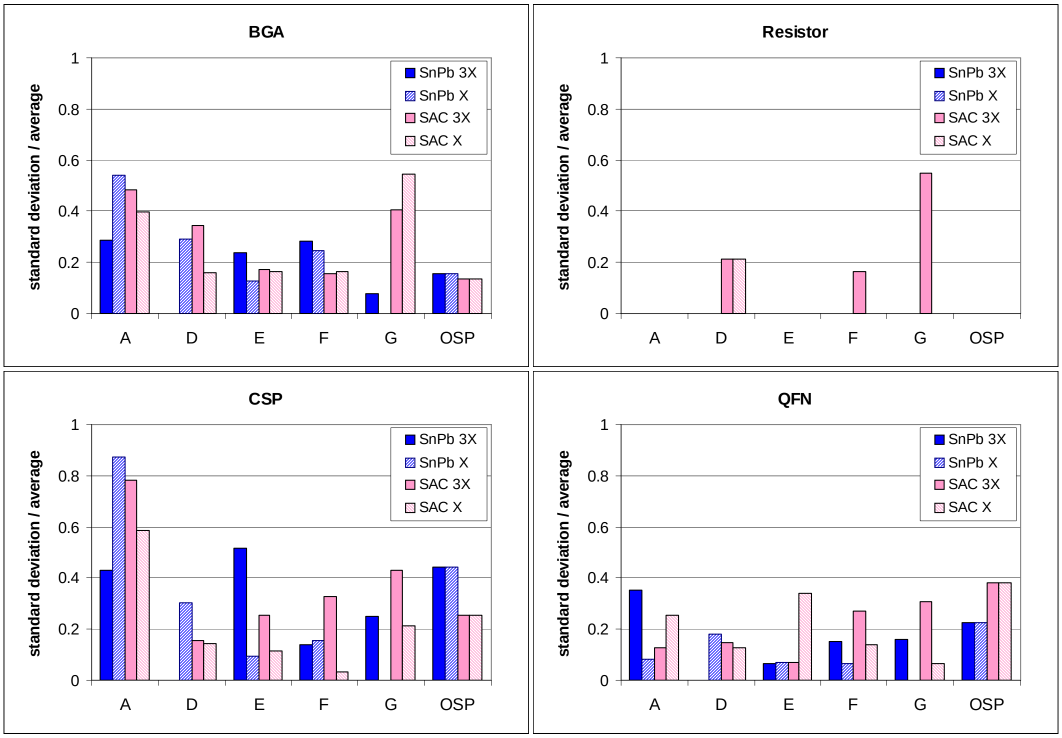

Figure 4 Failure Data Standard Deviations (Normalized by Averages)

BGA		A	D	E	F	G	OSP
SnPb	3X	19		6	22	21	4
	X	16	2	1	20		4
SAC	3X	17	3	8	15	18	12
	X	9	7	10	10	14	12

Resistor		A	D	E	F	G	OSP
SnPb	3X	22		16	21	13	19
	X	11	10	15	17		19
SAC	3X	18	2	1	12	9	4
	X	7	2	4	7	13	4

CSP		A	D	E	F	G	OSP
SnPb	3X	17		12	21	22	2
	X	5	4	1	14		2
SAC	3X	13	7	9	18	19	10
	X	16	6	8	15	20	10

QFN		A	D	E	F	G	OSP
SnPb	3X	20		4	7	19	5
	X	3	10	9	2		5
SAC	3X	22	11	1	17	21	13
	X	15	12	18	8	16	13

Figure 5 Ranks for Average Thermal Cycles by Component

Overall, the impact of surface finish on the average reliability was much more significant on the larger, high I/O components (the BGA's and CSP's). This is indicated in both the variations of average lifetimes for a given component style with different surface finish and solderpaste combinations, as well as the range of error bars (standard deviation) indicated in Figure 3. The variability trends are more thoroughly explored in Figure 4, which presents the standard deviation normalized by the average, for each combination in the test matrix. Again the results for Resistors are not considered significant due to the limited sample sizes. Figure 4 again shows that the area array components had greater variability in the failure data, with surface finish A appearing to be slightly more variable than the others.

As a final means of assessing the failure data generated in this study, Figure 5 shows how the average fatigue life for each combination for a particular component ranks with respect to all the other combinations. For example, in the BGA testing the component with SnPb X solderpaste and surface finish E had an average life of 807 thermal cycles (this is shown graphically in Figure 3), which was the longest average life of any BGA combination in the test. Therefore, this combination ranks first for BGA's as shown in Figure 5. Similarly, SnPb 3X with surface finish G had the lowest average life of all the BGA combinations tested and therefore ranked 22nd (with two possible combinations in the 4x6 matrix having no samples tested). Some level of color coding is used in Figure 5 to demonstrate general trends: ranks of 1-5 (longest lifetimes) are shown in **bold/green** with yellow background, ranks of 18 and higher (shortest lifetimes) are shown in ***red/italic***. If one ignores the results for Resistors based on the small sample sizes, the trends for the other components indicated in Figure 5 are relatively consistent. Thirteen of the fifteen top-5 ranked parts for BGA's, CSP's and QFN's were components with SnPb solderpaste, with the majority of these with X rather than 3X thicknesses. On the area array components, nine out of ten of the worst performers were associated with surface finishes F or G. With only a few exceptions (QFNs with SAC X solderpaste and Resistors with SnPb solderpaste), all combinations with surface finishes D and E had rankings in the top half. The OSP surface finish, especially with SnPb solderpaste, also led to longer lifetimes (except for the single samples on the Resistors).

Test Results: Failure Analysis

Failure analysis of the test vehicle components was conducted using metallographic analysis, and scanning electron microscopy (SEM) elemental mapping analysis. The metallographic analysis was conducted to characterize the solder joint failures and solder joint microstructures. The SEM elemental mapping analysis was conducted to characterize the silver distribution in the solder joint microstructure and the solder joint failure regions. Appendix A contains Figures 9 thru 28 illustrating the failure analysis results for one chemistry supplier for both the tin/lead and lead-free soldering processes. A complete set of metallographic and SEM failure analysis results for all chemistry suppliers and test vehicles will be published by the IPC Plating Process 4-14 committee as part of the committee specification revision activities.

DISCUSSION

A review of the statistical and physical failure analysis results is summarized in the following sections:

The Impact of Solder Joint Voiding

A significant amount of physical failure analysis effort was devoted to determining the possible impact of voids on the solder joint integrity. A large number of industry reports [2, 3, 4] have documented the degradation of solder joint integrity due to presence of "champagne voids" resulting from improper plating process control. Figure 6 illustrates an example of champagne voids in a solder joint [6]. Arguably, no evidence of champagne voiding was observed in the completed metallographic cross sections. However, a number of the metallographic samples document the presence of "typical macro voiding" for the various immersion silver plating combinations. The authors do not believe that the voiding observed confounded the overall solder joint integrity measurements. Coyle et al concluded that solder voiding reduced the solder joint integrity only when the voids were in the crack propagation path, thus reducing the overall necessary crack propagation length necessary for solder joint failure [5]. The voiding phenomenon observed in this investigation is in agreement with the Coyle test results/conclusions.

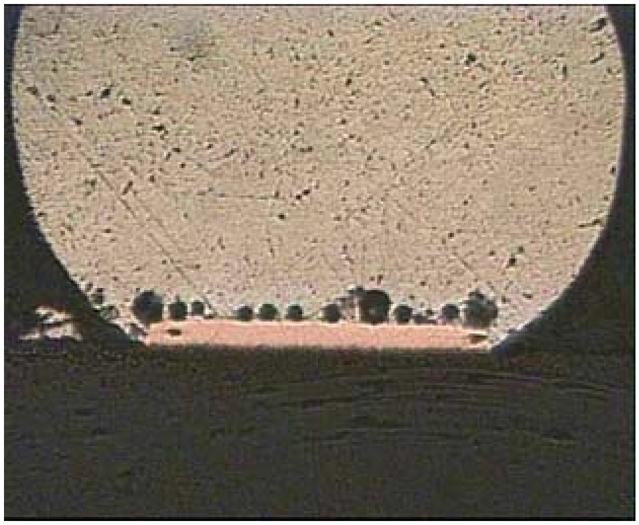

Figure 6 Champagne Voids in a Solder Joint [6]

Area Array Component Failure Location and Proposed Root Cause

The physical failure analysis revealed one observation of significant interest. The BGA and CSP component soldered with the SnPb solder alloy all had failure locations at the solderball/test vehicle interface. The BGA and CSP components soldered with the SAC solder alloy all had failure locations at the solderball/component pad interface. This observation was independent of immersion silver plating thickness. Figure 7 illustrates a SnPb and SAC typical area array component failure location observation examples. A number of industry investigations [7, 8, 9] have shown that the mixed metallurgy composition of a lead-free soldersphere processed in a tin/lead soldering process (e.g. a SAC405 solderball soldered with a Sn63Pb37 solder paste) has degraded thermal cycle solder joint integrity. The proposed failure root cause is the presence of lead in the crack path resulting in solder joint degradation. Figure 8 illustrates the proposed failure root cause showing a mixed metallurgy BGA solder joint and the segregation of lead in the failure crack path of a BGA solder joint [7].

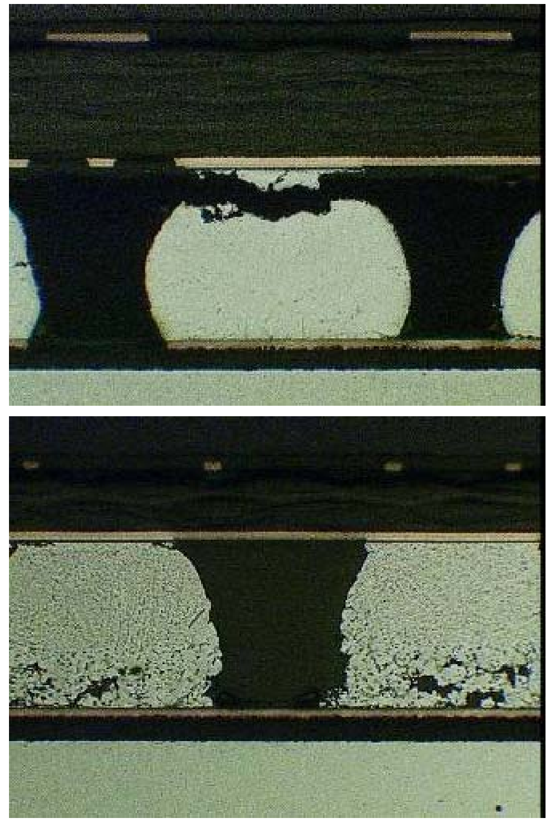

Figure 7 Top: SAC BGA Solder Joint, Bottom: SnPb BGA Solder Joint

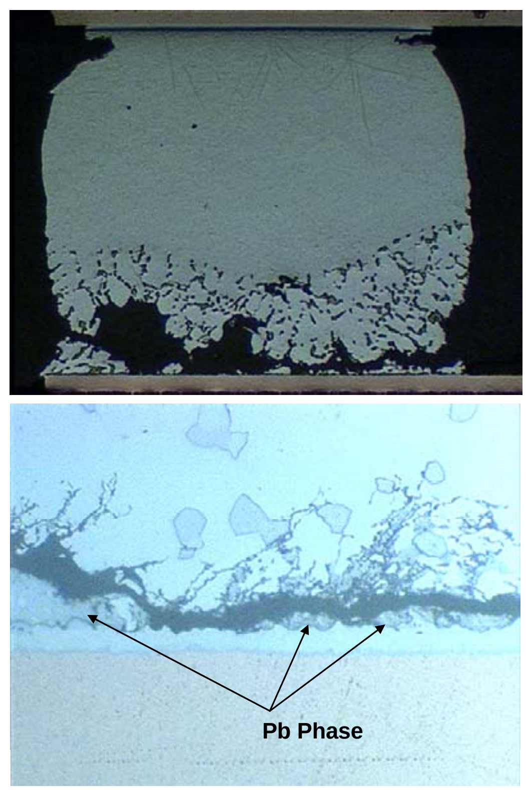

Figure 8 Mixed Metallurgy Solder Joint Failure Root Cause (bottom photo from reference [7])

Scanning Electron Microscopy (SEM) Elemental Mapping Analysis

One of the primary concerns of the IPC Plating Processes subcommittee 4-14 was "silver loading" of the solder joints. The subcommittee speculated that the combined contributions of the immersion silver surface finish, silver content of the BGA soldersphere and the silver content of the SAC305 solder paste could result in either a metallurgical or process driven silver segregation issue. SEM elemental mapping analysis was conducted to determine if the silver loading concern could be substantiated. SEM elemental mapping serves two purposes; (1) any silver rich solder joint regions due to improper solder joint reflow/incorrect soldering process procedures would be evident; (2) any silver rich microstructure phase reactions, such as tin/silver intermetallic phases, would be evident. Over 100 SEM elemental map analyses were completed and no indications of either metallurgical or process sourced silver loading occurrences resulted in solder joint failure.

OSP Test Vehicle Observations

The OSP surface finished test vehicles served as the baseline data for comparison to the various immersion silver surface finished test vehicles. A review of Figure 5 shows that the OSP test vehicles consistently achieved the best performance rankings (with consideration for the sample size influence on the Resistor data).

Immersion Silver Thickness Observations

The primary objective of the investigation was to assess the impact of immersion silver printed wiring board surface finish used in either a tin/lead or a lead-free soldering process on solder joint integrity for a -55ºC to +125ºC thermal cycle temperature range. A review of the Figure 5 rankings shows that, in general, the typical immersion silver plating thicknesses (e.g. "X") out performed the extreme immersion plating thicknesses (e.g. "3X") for both the tin/lead and SAC solder processes. Additionally, the impact of the extreme immersion plating thicknesses was more pronounced on the tin/lead solder process than the SAC solder process. Hillman et al [10] showed that a maximum limit of 32 micro-inches of immersion silver had a statistically significant impact on the solder joint thermal cycle integrity. The investigation results are in agreement with the Hillman investigation results/conclusions. Chen and Dutta [11] investigated the impact of increasing the silver and copper concentrations on the creep rate of selected tin based solder alloys. Their test results showed that the creep rates of their studied tin based solder alloys decreased with increasing silver and copper concentrations. A lower creep rate would correspond to a less compliant solder joint thereby making it more susceptible to cracking during thermal cycling. The thicker test vehicle silver surface finish resulted in decreased solder joint integrity possible due to a similar effect. These test results would support the use of a maximum immersion silver surface thickness in the 15-30 micro-inch range. Other factors, such as critical plating process parameters or printed wiring board feature influences, may be considered to further refine the maximum immersion silver plating thickness value.

CONCLUSION

The investigation test results and data analysis demonstrate that the immersion silver printed wiring board surface finish used in either a tin/lead or a lead-free soldering process has an impact on the solder joint integrity for a -55ºC to +125ºC thermal cycle temperature range.

RECOMMENDATION

The IPC Plating Processes subcommittee 4-14 should review the current IPC-4553 maximum immersion silver plating thickness value and consider implementing a maximum immersion silver surface thickness in the 15-30 micro-inch range. Other factors, such as critical plating process parameters or printed wiring board feature influences, may be considered to further refine the maximum immersion silver plating thickness value.

ACKNOWLEDGEMENTS

The authors would like to thank the IPC Plating Processes subcommittee 4-14 for the opportunity to participate the testing effort, Ken Blazek for metallography efforts, and Sig Schmolling for SEM analysis efforts.

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11 T. Chen and I. Dutta, "Effect of Ag and Cu Concentrations on the Creep Behavior of Sn Based Solders", Journal of Electronic Materials, Volume 37, Number 3, 2008.

Appendix A
SnPb Soldering Process:

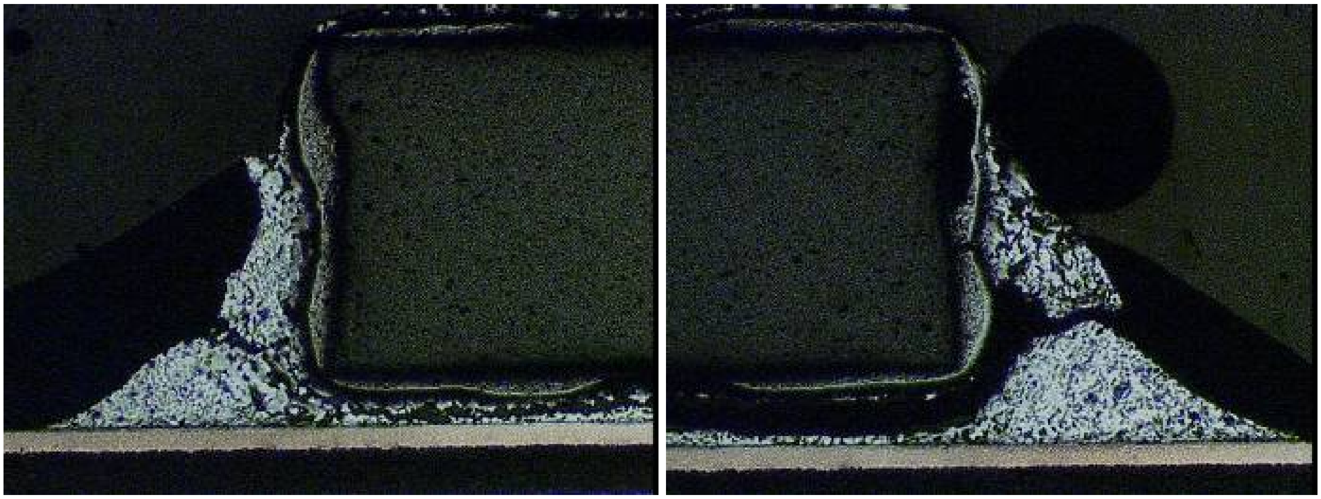

Figure 9: Chemistry Supplier A, Thickness X, Resistor, TV1, Location 9, Failed 133 Cycles, SnPb

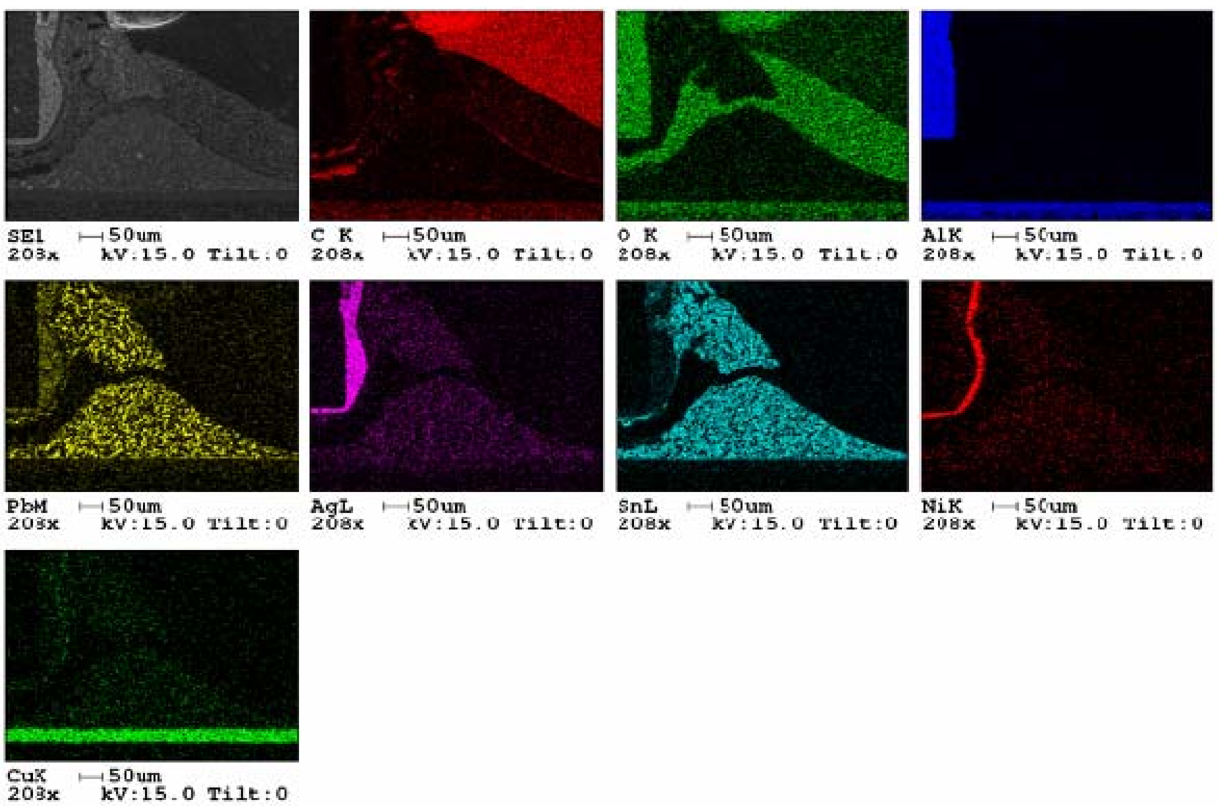

Figure 10: SEM Elemental Mapping Results for TV1, Resistor, Chemistry Supplier A, Thickness X, SnPb

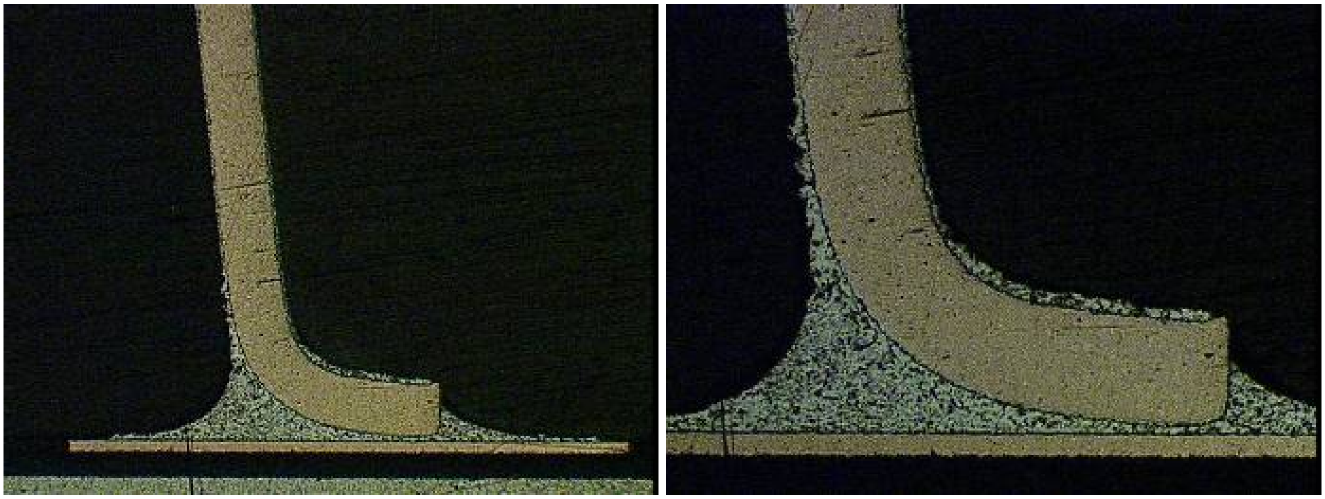

Figure 11: Chemistry Supplier A, Thickness X, QFP208, TV1, Location 7, No Failure, SnPb

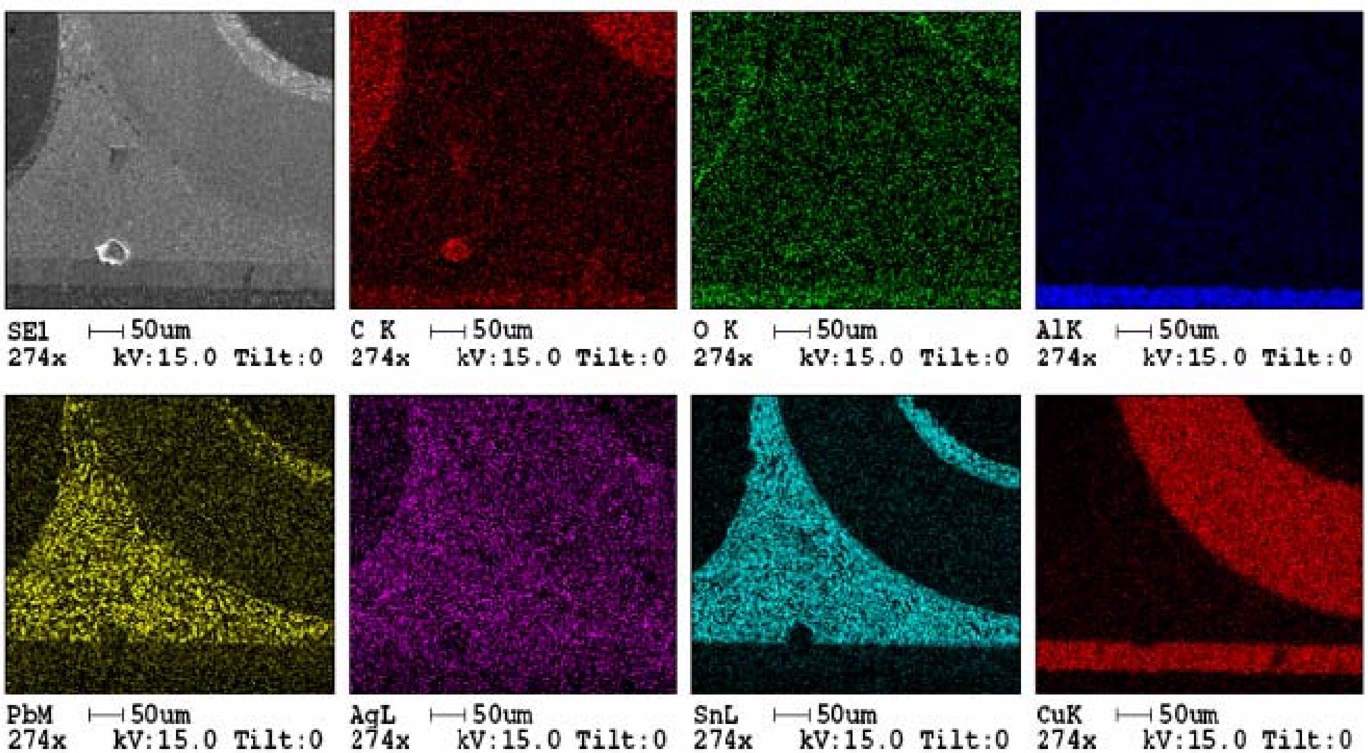

Figure 12: SEM Elemental Mapping Results for TV1, QFP208, Chemistry Supplier A, Thickness X, SnPb

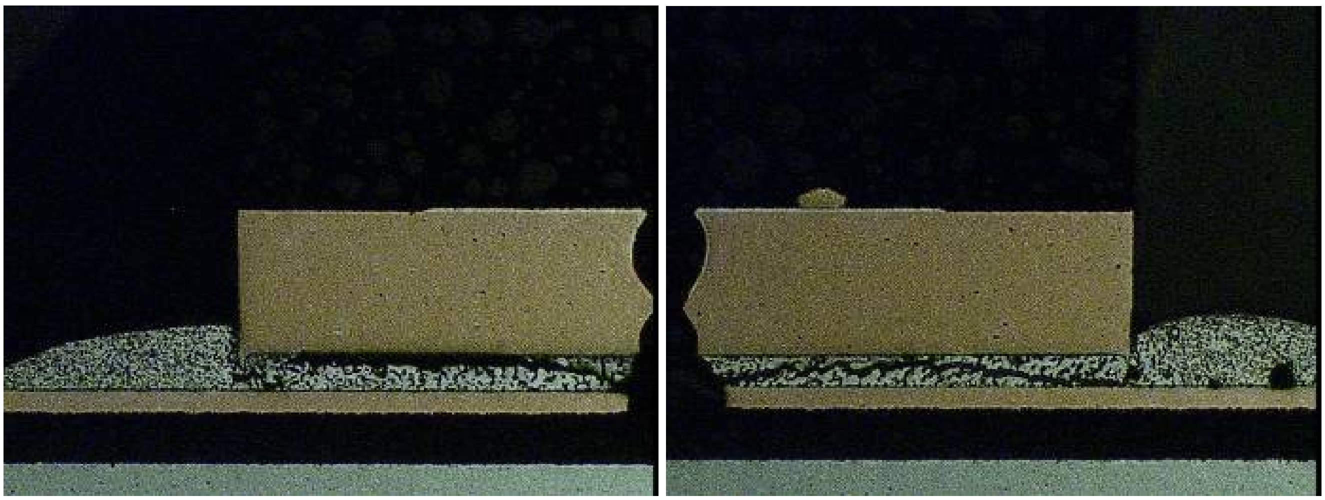

Figure 13: Chemistry Supplier A, Thickness X, QFN, TV1, Location 9, Failed 524 Cycles, SnPb

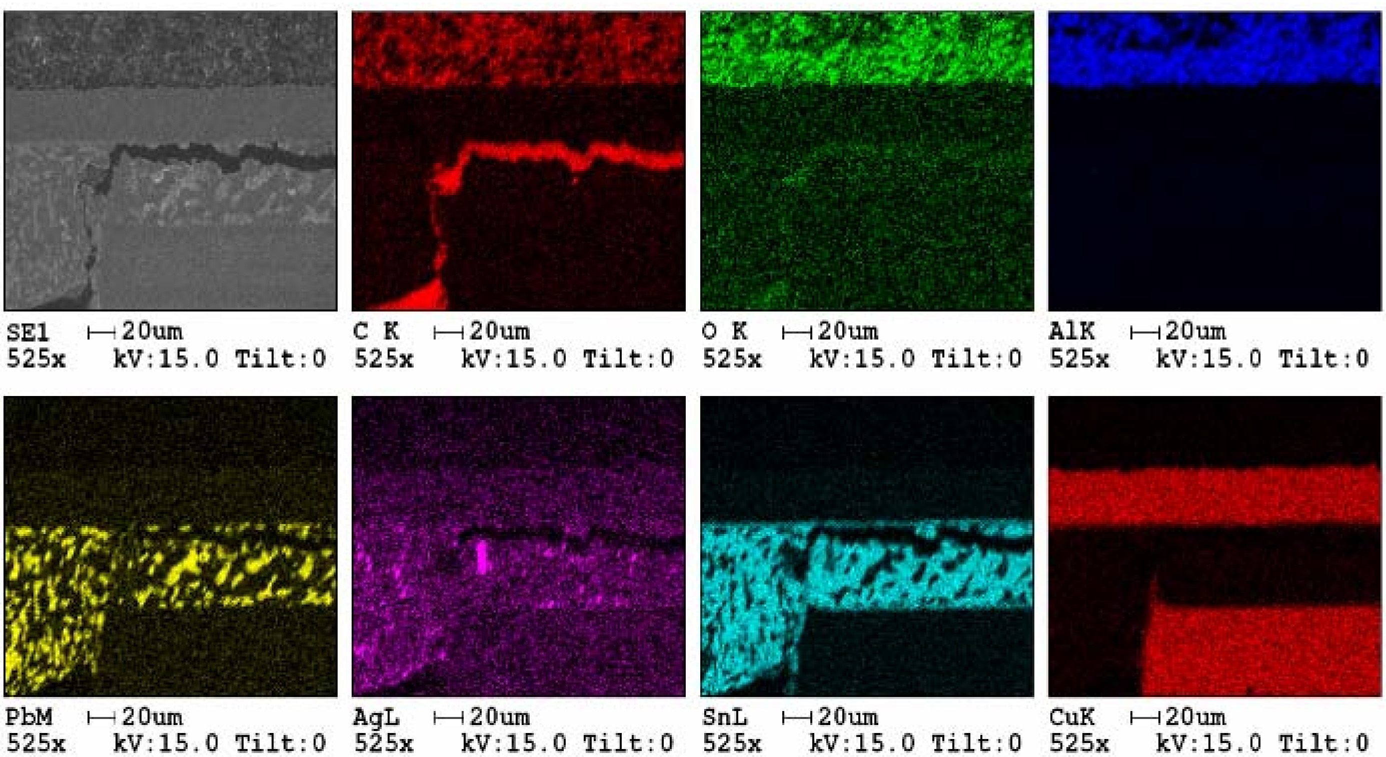

Figure 14: SEM Elemental Mapping Results for TV1, QFN, Chemistry Supplier A, Thickness X, SnPb

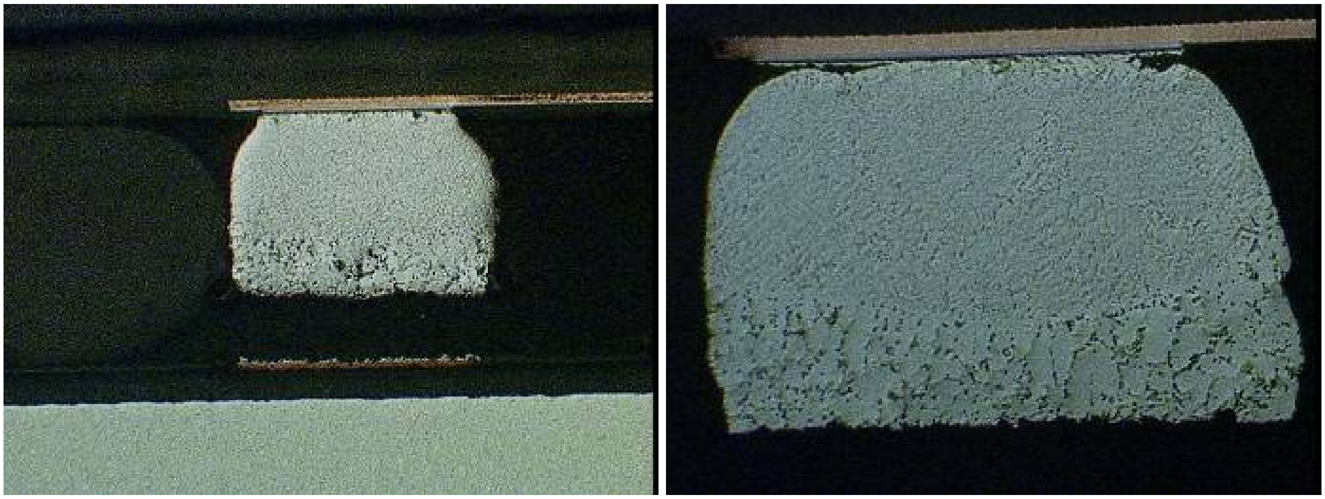

Figure 15: Chemistry Supplier A, Thickness X, CSP, TV1, Location 9, Failed 520 Cycles, SnPb

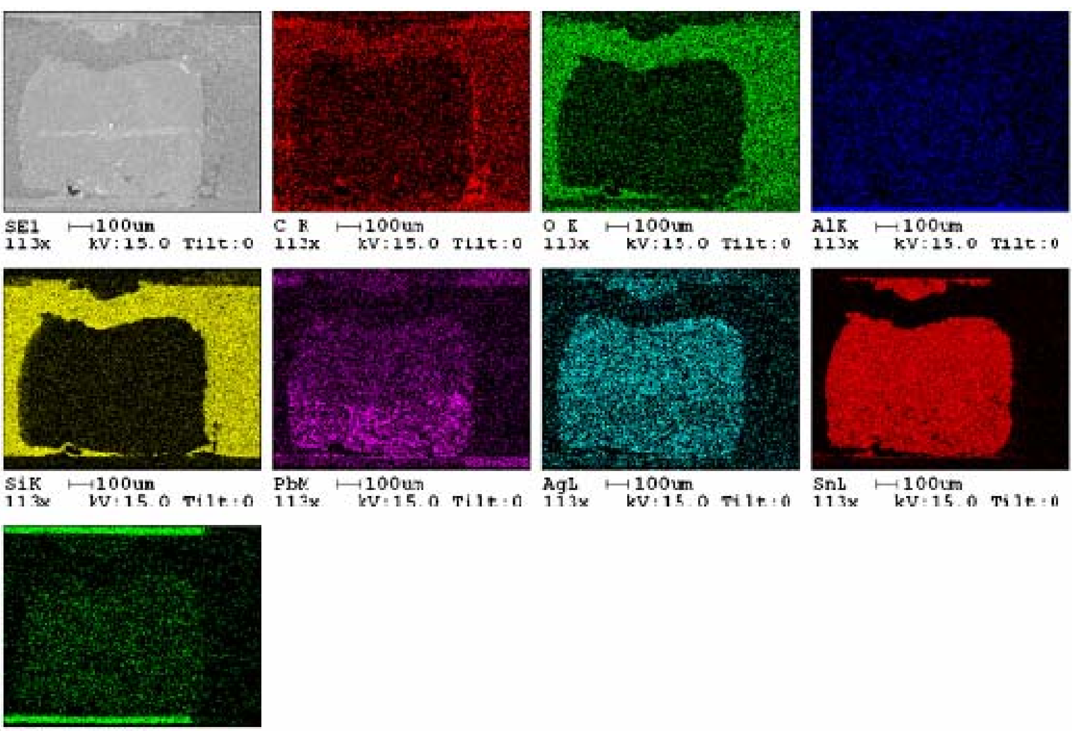

Figure 16: SEM Elemental Mapping Results for TV1, CSP, Chemistry Supplier A, Thickness X, SnPb

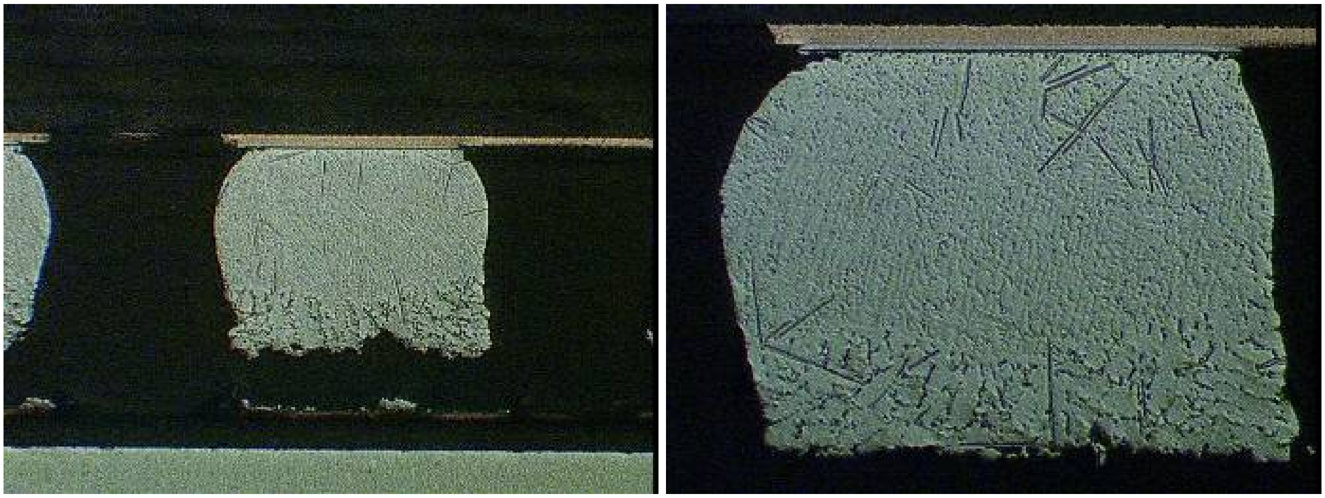

Figure 17: Chemistry Supplier A, Thickness X, BGA, TV1, Location 3, Failed 308 Cycles, SnPb

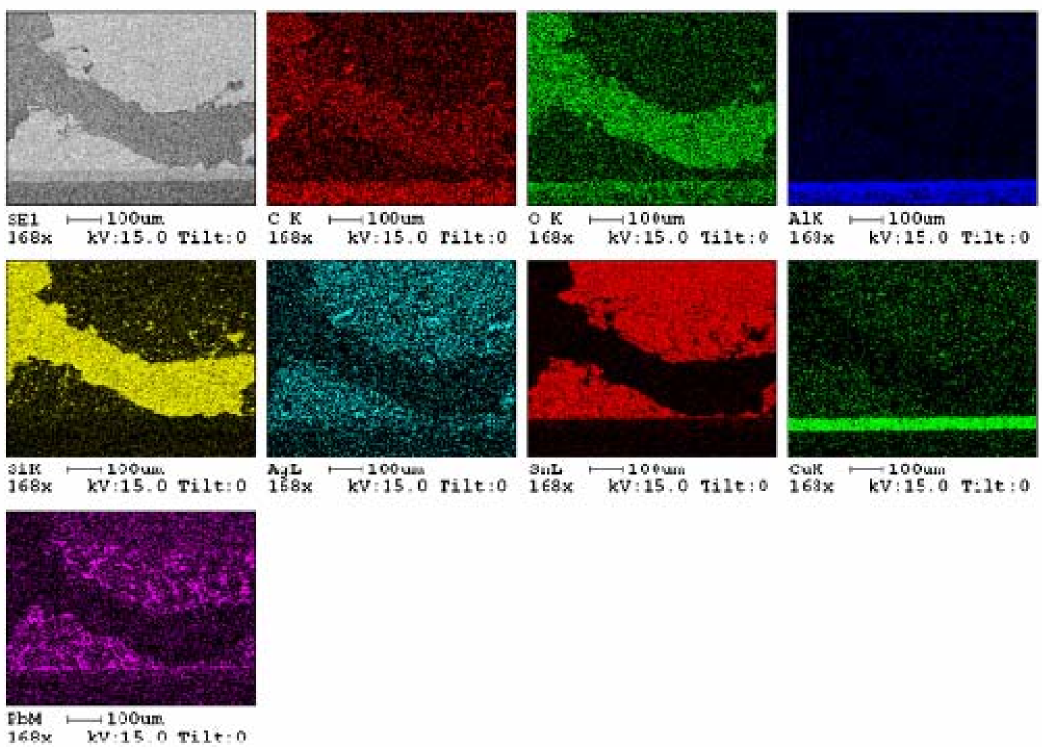

Figure 18: SEM Elemental Mapping Results for TV1, BGA, Chemistry Supplier A, Thickness X, SnPb

SAC Soldering Process:

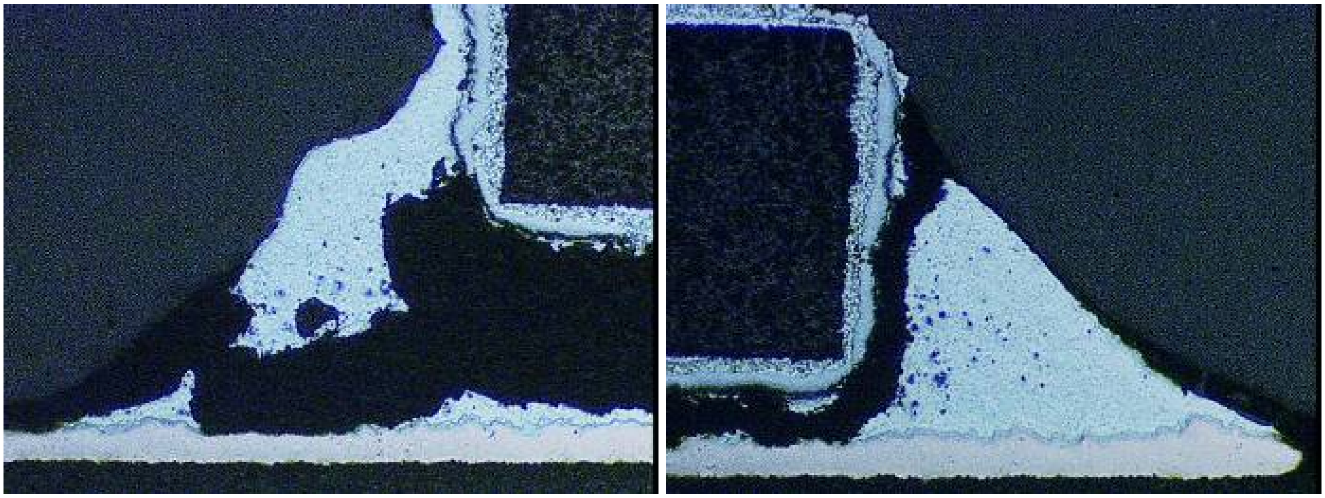

Figure 19: Chemistry Supplier A, Thickness X, Resistor, TV11, Location 9A, Failed 385 Cycles, SAC

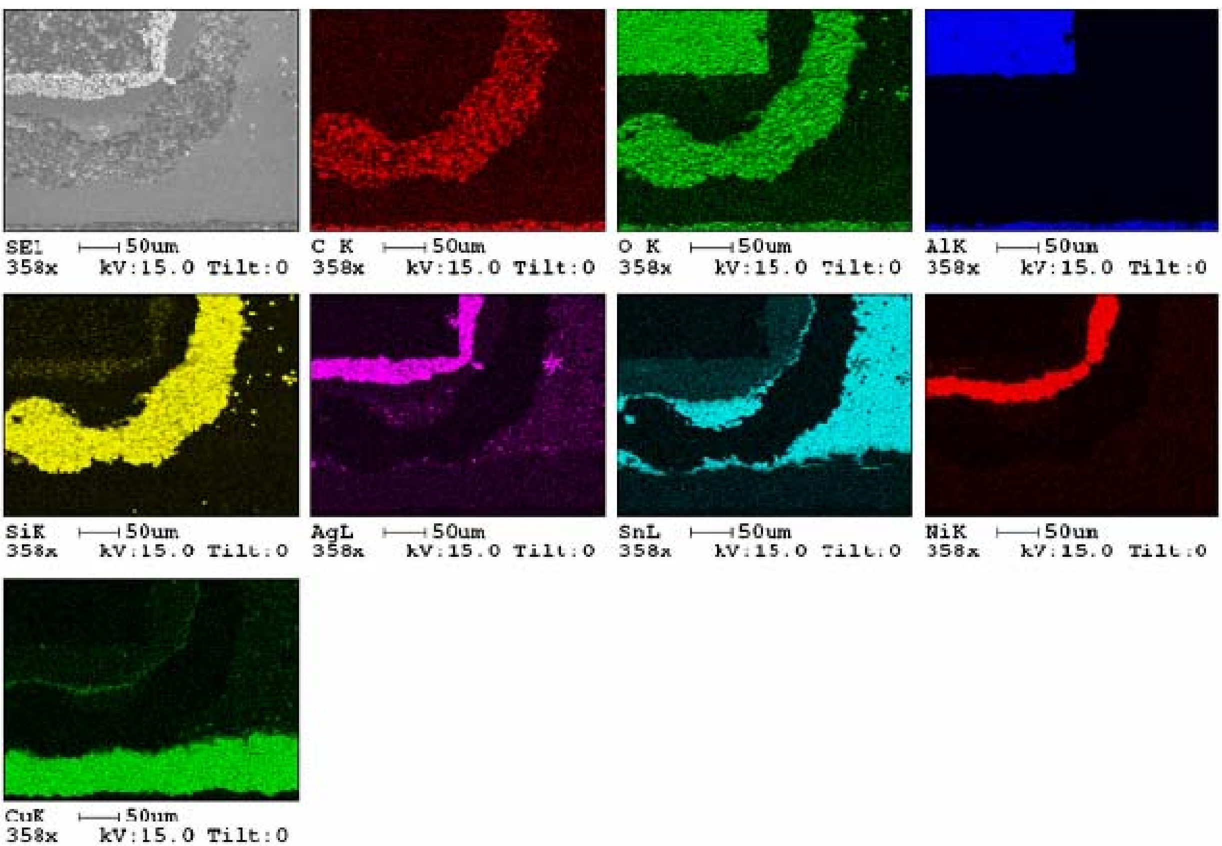

Figure 20: SEM Elemental Mapping Results for TV11, Resistor, Chemistry Supplier A, Thickness X, SAC

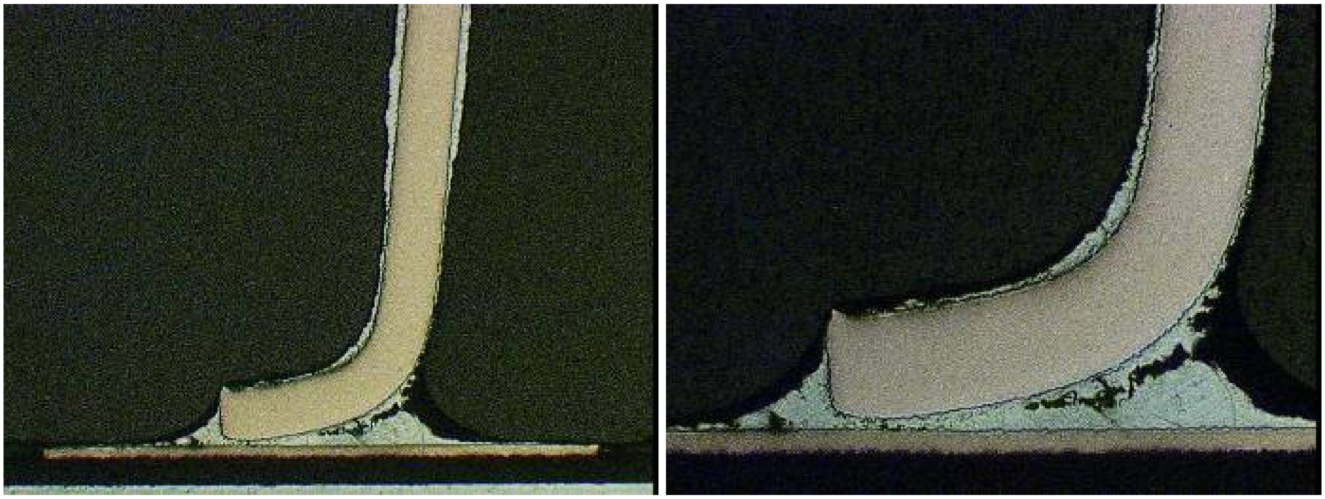

Figure 21: Chemistry Supplier A, Thickness X, QFP208, TV11, Location 7, No Failure, SAC

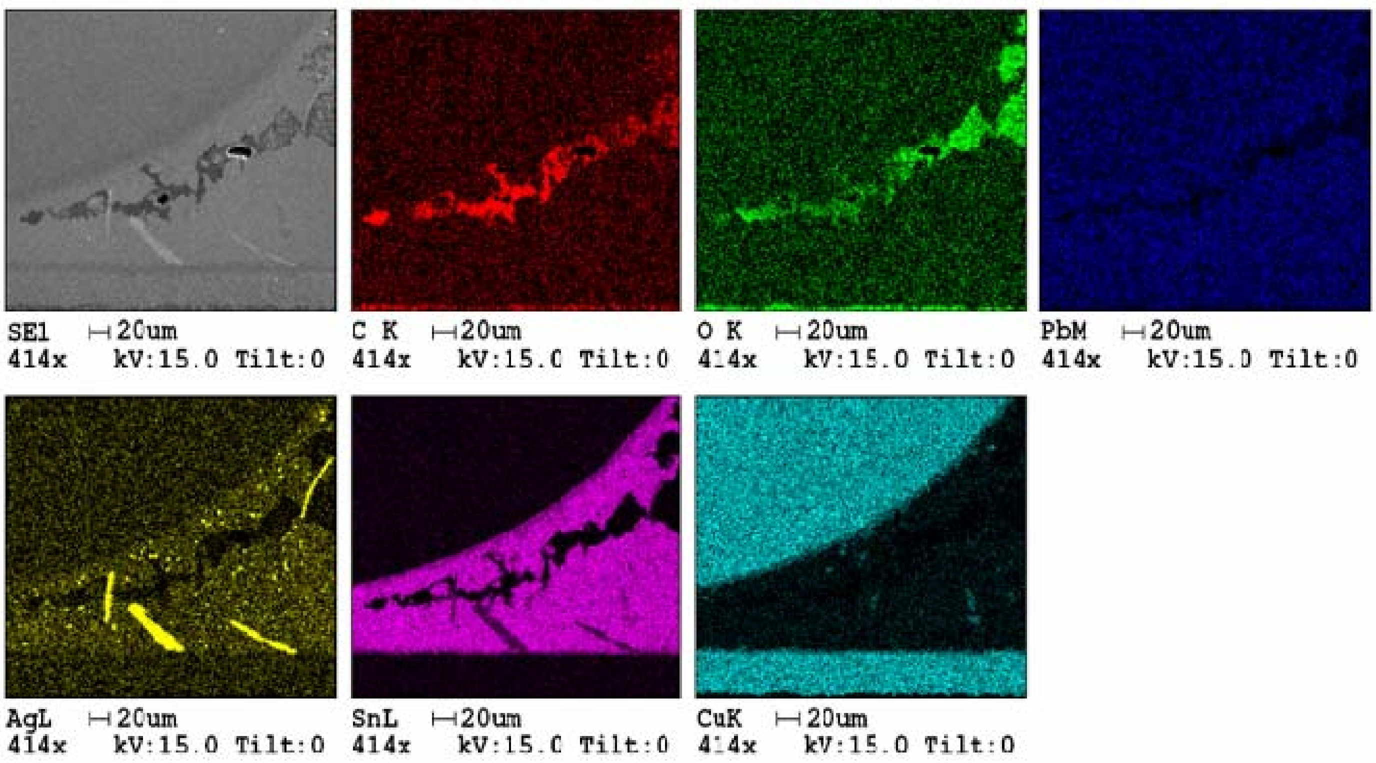

Figure 22: SEM Elemental Mapping Results for TV11, QFP208, Chemistry Supplier A, Thickness X, SAC

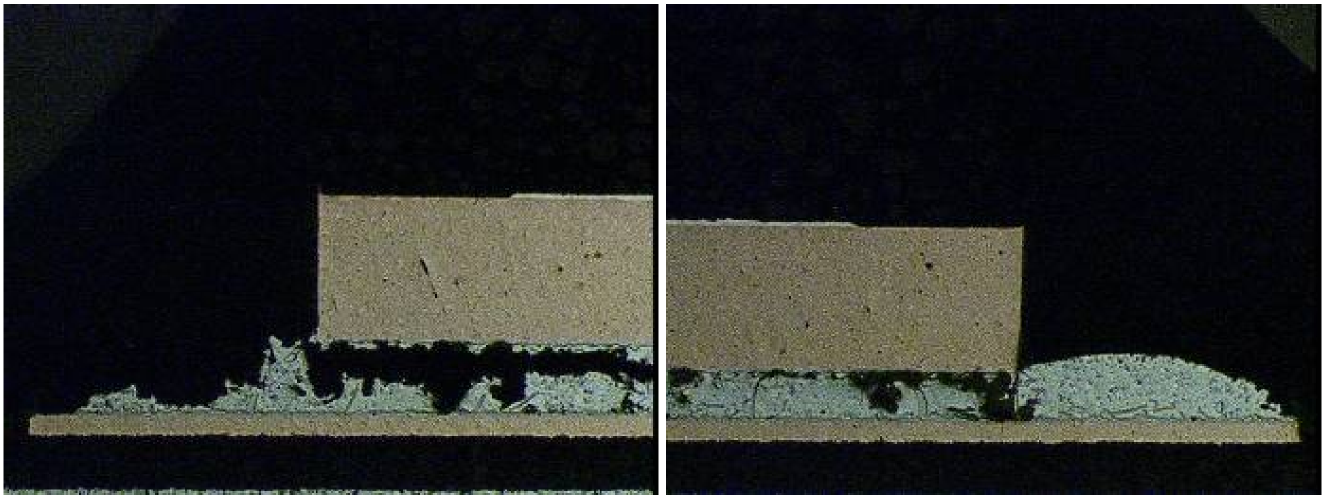

Figure 23: Chemistry Supplier A, Thickness X, QFN, TV11, Location 11, Failed 401 Cycles, SAC

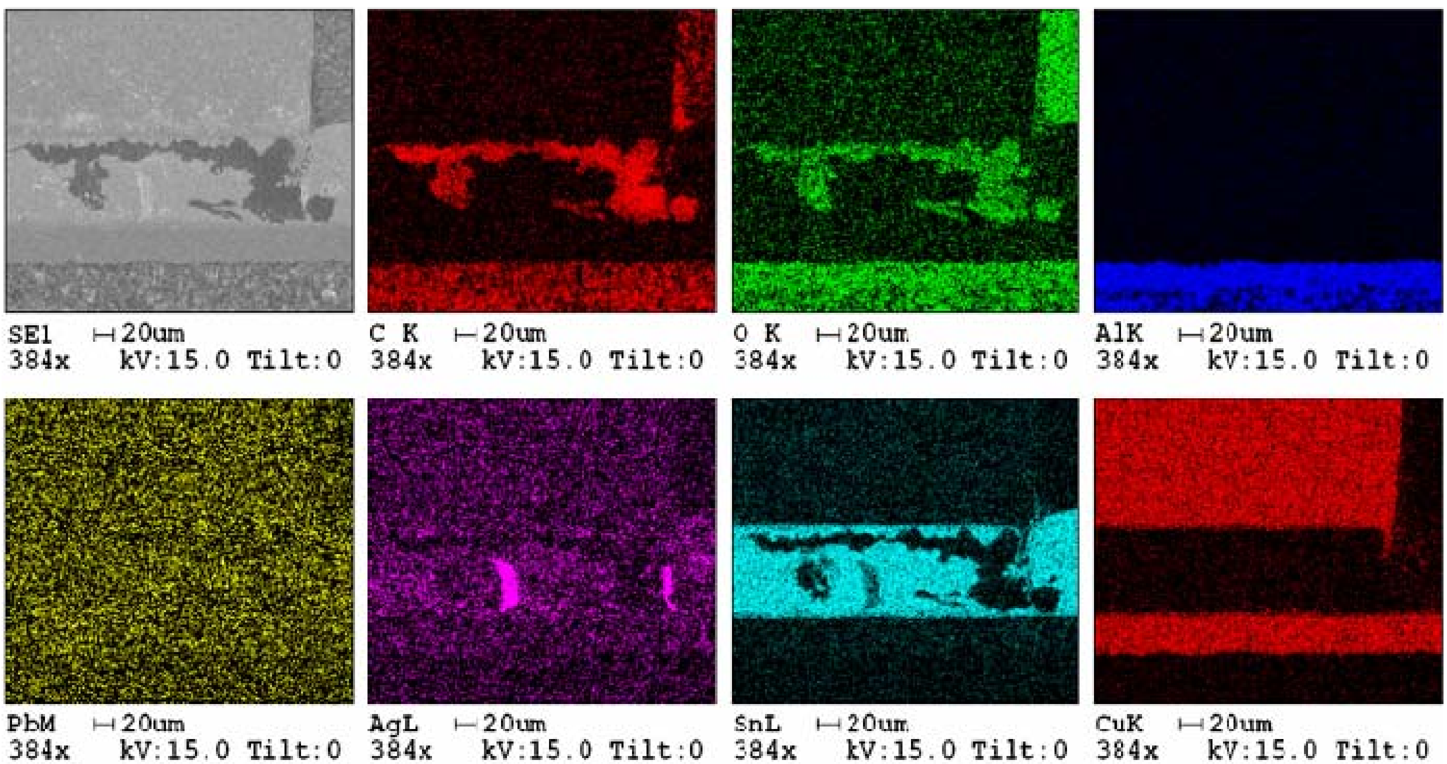

Figure 24: SEM Elemental Mapping Results for TV11, QFN, Chemistry Supplier A, Thickness X, SAC

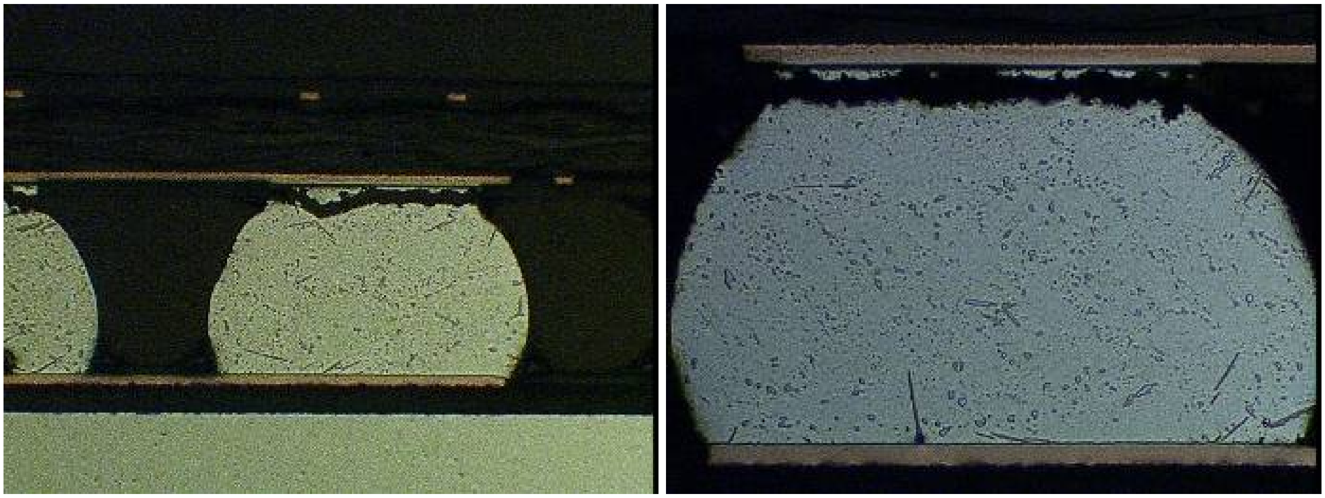

Figure 25: Chemistry Supplier A, Thickness X, CSP, TV11, Location 13, Failed 458 Cycles, SAC

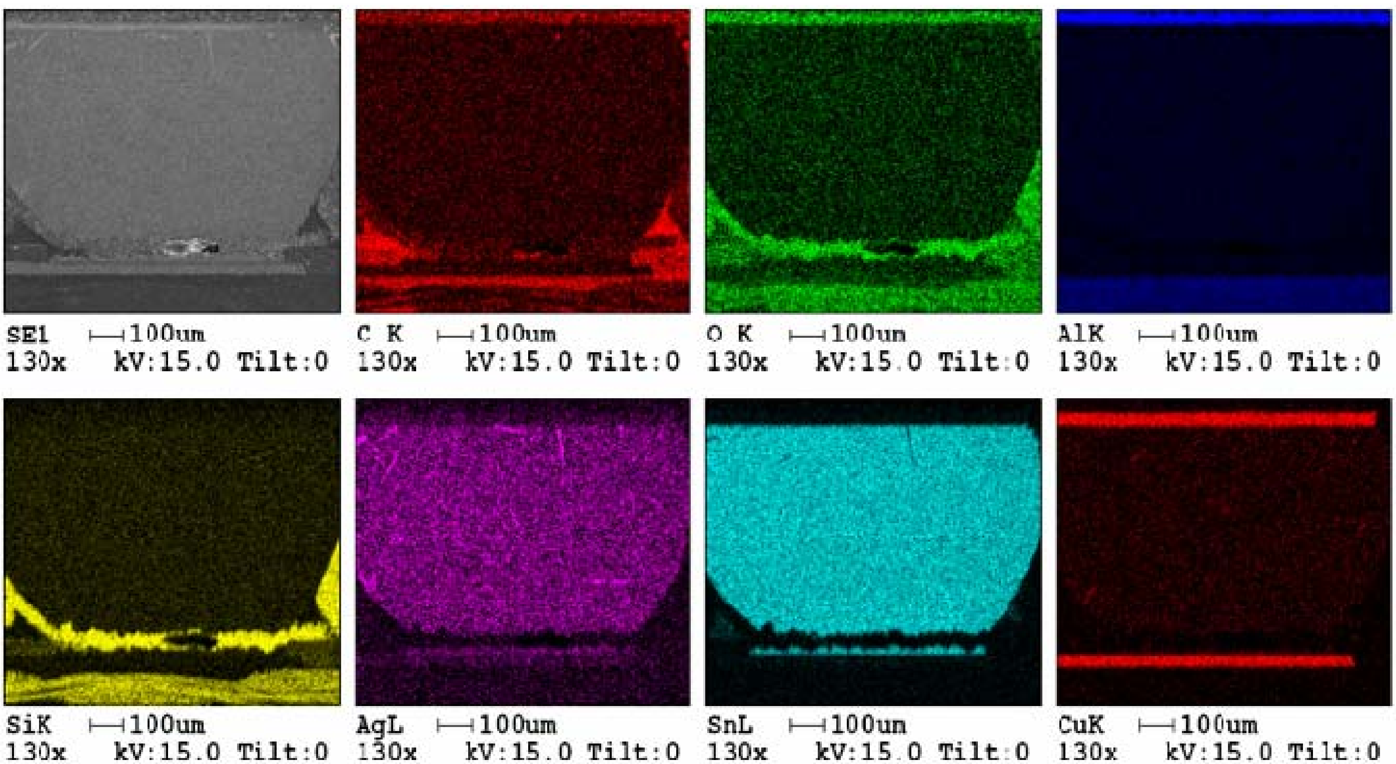

Figure 26: SEM Elemental Mapping Results for TV11, CSP, Chemistry Supplier A, Thickness X, SAC

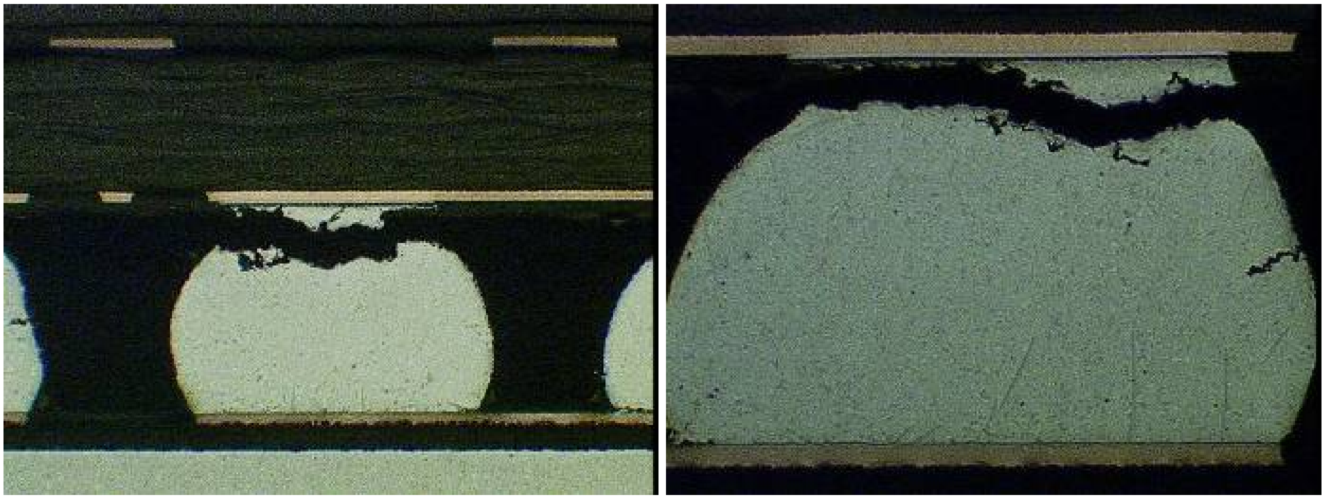

Figure 27: Chemistry Supplier A, Thickness X, BGA, TV11, Location 3, Failed 386 Cycles, SAC

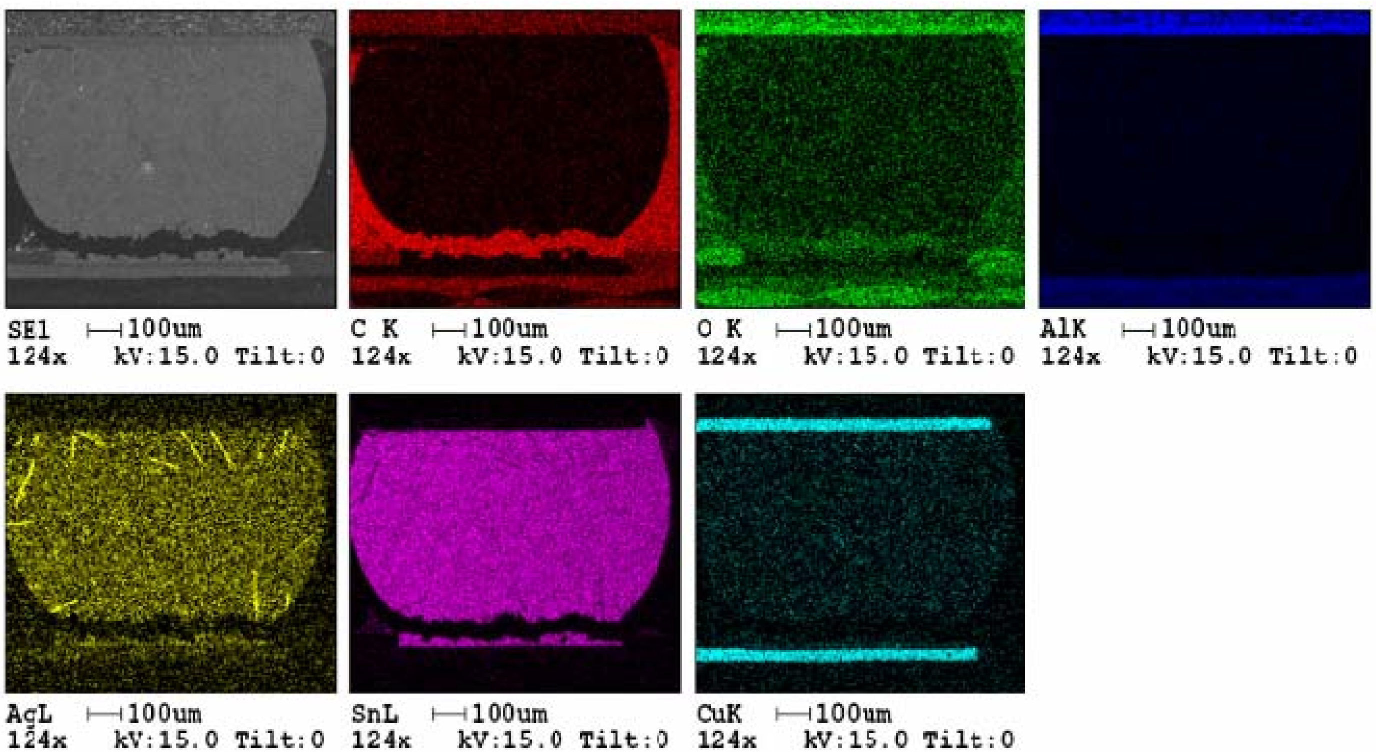

Figure 28: SEM Elemental Mapping Results for TV11, BGA, Chemistry Supplier A, Thickness X, SAC

Mass and Volume Fraction Calculations for 63Sn37Pb and SAC305 Solder Joints on Immersion Silver PCBs

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ABSTRACT

The purpose of these mass and volume calculations was to determine if there is a correlation between the amount of Ag_3Sn intermetallic compound (IMC) in various solder joints and their long term reliability. This understanding, in turn, would be useful in establishing an immersion silver thickness upper limit. The immersion silver (IAg) coupons in this study were divided into two subgroups – those with a single Ag thickness application and those with a 3x thickness application. Although the latter would typically be considered outside of normal process conditions, it was desired to be able to draw distinctions among a larger Ag thickness range than simply the variation within the single thickness application group. It should be noted that all Ag was considered to go into the formation of the IMC Ag_3Sn, i.e. no free silver, since this is thermodynamically favorable under these conditions. Likewise noteworthy is the limited impact of the thicker (3x) IAg layer on the mass and volume fractions of Ag_3Sn for the PBGA256 joints. This is attributable to the much larger overall volume contribution by the BGA ball.

It was concluded by Hillman et al that the IAg thickness does have an impact on solder joint reliability for a -55°C to 125°C thermal cycling profile. Subsequently, the IPC 4-14 committee has put forth the IAg suggested upper thickness limit of 16 microinches. From this, and using the information following, it is implied that the *additional* mass fraction of Ag_3Sn contributed by the IAg finish should ideally be no more than about 1%.

ELEMENTAL COMPOSITION

Component	ImAg Vendor	ImAg Thickness	Paste Alloy	Wt% Sn	Wt%Pb	Wt%Ag	Wt%Cu
QFP208	A	Standard	63Sn37Pb	62.9	36.3	0.8	0.0
		3X	63Sn37Pb	62.0	35.8	2.2	0.0
		Standard	SAC305	95.7	0.0	3.8	0.5
		3X	SAC305	94.1	0.0	5.4	0.5
	F	Standard	63Sn37Pb	63.0	36.4	0.6	0.0
		3X	63Sn37Pb	62.5	36.0	1.5	0.0
		Standard	SAC305	96.0	0.0	3.5	0.5
		3X	SAC305	94.9	0.0	4.6	0.5
	G	Standard	63Sn37Pb	62.8	36.2	1.0	0.0
		3X	63Sn37Pb	61.5	35.5	3.0	0.0
		Standard	SAC305	95.5	0.0	4.0	0.5
		3X	SAC305	93.3	0.0	6.2	0.5
QFN 4mm x 4mm	A	Standard	63Sn37Pb	63.3	36.1	0.6	0.0
		3X	63Sn37Pb	62.3	35.4	2.3	0.0
		Standard	SAC305	95.8	0.0	3.7	0.5
		3X	SAC305	94.0	0.0	5.5	0.5
	F	Standard	63Sn37Pb	63.3	36.0	0.7	0.0
		3X	63Sn37Pb	62.7	35.6	1.7	0.0
		Standard	SAC305	95.8	0.0	3.7	0.5
		3X	SAC305	94.5	0.0	5.0	0.5
	G	Standard	63Sn37Pb	63.2	36.0	0.8	0.0
		3X	63Sn37Pb	61.8	35.3	2.9	0.0
		Standard	SAC305	95.7	0.0	3.8	0.5
		3X	SAC305	93.4	0.0	6.1	0.5
PBGA256	A	Standard	63Sn37Pb	92.5	3.3	3.7	0.5
		3X	63Sn37Pb	92.3	3.3	3.9	0.5
		Standard	SAC305	95.5	0.0	4.0	0.5
		3X	SAC305	95.4	0.0	4.1	0.5
	F	Standard	63Sn37Pb	92.5	3.3	3.7	0.5
		3X	63Sn37Pb	92.4	3.3	3.8	0.5
		Standard	SAC305	95.5	0.0	4.0	0.5
		3X	SAC305	95.4	0.0	4.1	0.5
	G	Standard	63Sn37Pb	92.5	3.3	3.7	0.5
		3X	63Sn37Pb	92.3	3.3	3.9	0.5
		Standard	SAC305	95.5	0.0	4.0	0.5
		3X	SAC305	95.3	0.0	4.2	0.5

EIA2512 Resistor	A	Standard	63Sn37Pb	63.8	35.9	0.3	0.0
		3X	63Sn37Pb	62.6	35.4	2.0	0.0
		Standard	SAC305	96.3	0.0	3.2	0.5
		3X	SAC305	94.4	0.0	5.1	0.5
	F	Standard	63Sn37Pb	63.7	35.9	0.4	0.0
		3X	63Sn37Pb	62.9	35.5	1.6	0.0
		Standard	SAC305	96.1	0.0	3.4	0.5
		3X	SAC305	94.9	0.0	4.6	0.5
	G	Standard	63Sn37Pb	63.8	35.9	0.3	0.0
		3X	63Sn37Pb	62.6	35.4	2.0	0.0
		Standard	SAC305	96.3	0.0	3.2	0.5
		3X	SAC305	94.4	0.0	5.1	0.5

NOTES:

1) Assumes a 5 mil stencil was used, and 5 mil paste deposit height was achieved
2) Paste volume shrinkage of 50% was assumed (from paste to reflowed solder)
3) Presumes a 1:1 print ratio (aperture area: pad area)
4) Matte Sn (100Sn) plating with a thickness of 3 µm was assumed for the QFP208, QFN, and EIA2512 resistor
5) Worst case ImAg thicknesses from the XRF measurements were used (from respective component pads)
6) Metal densities are from Callister text; pure metals at 25°C
7) Thermodynamic data from NIST Metallurgical Database
8) BGA ball alloy was presumed to be SAC405
9) Mass and volume fraction calculations presume equilibrium freezing; actual freezing is non-equilibrium (Scheil), so actual wt% and vol% of phases will vary; resulting metastable phases and kinetics are not accounted for

QFP208 - PHASE MASS FRACTIONS

Sn-Ag-Cu System

Vendor A Std.	Mass Fraction		Vendor F Std.	Mass Fraction		Vendor G Std.	Mass Fraction	
0.957	0.9362	**(Sn)**	0.960	0.94027	**(Sn)**	0.955	0.93343	**(Sn)**
0.038	0.0510	**Ag_3Sn**	0.035	0.04693	**Ag_3Sn**	0.040	0.05377	**Ag_3Sn**
0.005	0.0128	**Cu_6Sn_5**	0.005	0.0128	**Cu_6Sn_5**	0.005	0.0128	**Cu_6Sn_5**

Sn-Pb-Ag System

Vendor A Std.			Vendor F Std.			Vendor G Std.		
0.629	0.5711	**(Sn)**	0.630	0.57263	**(Sn)**	0.628	0.56947	**(Sn)**
0.363	0.4184	**(Pb)**	0.364	0.41954	**(Pb)**	0.362	0.41723	**(Pb)**
0.008	0.0106	**Ag_3Sn**	0.006	0.00783	**Ag_3Sn**	0.010	0.0133	**Ag_3Sn**

Sn-Ag-Cu System

Vendor A 3X			Vendor F 3X			Vendor G 3X		
0.941	0.9143	**(Sn)**	0.949	0.92522	**(Sn)**	0.933	0.90333	**(Sn)**
0.054	0.0729	**Ag_3Sn**	0.046	0.06198	**Ag_3Sn**	0.062	0.08387	**Ag_3Sn**
0.005	0.0128	**Cu_6Sn_5**	0.005	0.0128	**Cu_6Sn_5**	0.005	0.0128	**Cu_6Sn_5**

Sn-Pb-Ag System

Vendor A 3X			Vendor F 3X			Vendor G 3X		
0.62	0.5574	**(Sn)**	0.625	0.56488	**(Sn)**	0.615	0.54985	**(Sn)**
0.358	0.4128	**(Pb)**	0.360	0.41498	**(Pb)**	0.355	0.4095	**(Pb)**
0.022	0.0297	**Ag_3Sn**	0.015	0.02013	**Ag_3Sn**	0.030	0.04064	**Ag_3Sn**

QFN4x4 - PHASE MASS FRACTIONS

Sn-Ag-Cu System

Vendor A Std.	Mass Fraction		Vendor F Std.	Mass Fraction		Vendor G Std.	Mass Fraction	
0.958	0.9375	**(Sn)**	0.958	0.9375	**(Sn)**	0.957	0.9362	**(Sn)**
0.037	0.0497	**Ag_3Sn**	0.037	0.0497	**Ag_3Sn**	0.038	0.0510	**Ag_3Sn**
0.005	0.0128	**Cu_6Sn_5**	0.005	0.0128	**Cu_6Sn_5**	0.005	0.0128	**Cu_6Sn_5**

Sn-Pb-Ag System

Vendor A Std.			Vendor F Std.			Vendor G Std.		
0.633	0.5764	**(Sn)**	0.633	0.5763	**(Sn)**	0.632	0.5748	**(Sn)**
0.361	0.4157	**(Pb)**	0.360	0.4145	**(Pb)**	0.360	0.4146	**(Pb)**
0.006	0.0078	**Ag_3Sn**	0.007	0.0092	**Ag_3Sn**	0.008	0.0106	**Ag_3Sn**

Sn-Ag-Cu System

Vendor A 3X			Vendor F 3X			Vendor G 3X		
0.940	0.9129	**(Sn)**	0.945	0.9197	**(Sn)**	0.934	0.9047	**(Sn)**
0.055	0.0743	**Ag_3Sn**	0.050	0.0675	**Ag_3Sn**	0.061	0.0825	**Ag_3Sn**
0.005	0.0128	**Cu_6Sn_5**	0.005	0.0128	**Cu_6Sn_5**	0.005	0.0128	**Cu_6Sn_5**

Sn-Pb-Ag System

Vendor A 3X			Vendor F 3X			Vendor G 3X		
0.623	0.5611	**(Sn)**	0.627	0.5671	**(Sn)**	0.618	0.5538	**(Sn)**
0.354	0.4078	**(Pb)**	0.356	0.4100	**(Pb)**	0.353	0.4069	**(Pb)**
0.023	0.0311	**Ag_3Sn**	0.017	0.0229	**Ag_3Sn**	0.029	0.0393	**Ag_3Sn**

PBGA256 - PHASE MASS FRACTIONS

Sn-Ag-Cu System

Vendor A Std.	Mass Fraction		Vendor F Std.	Mass Fraction		Vendor G Std.	Mass Fraction	
0.955	0.9334	(Sn)	0.955	0.9334	(Sn)	0.955	0.9334	(Sn)
0.040	0.0538	Ag_3Sn	0.040	0.0538	Ag_3Sn	0.040	0.0538	Ag_3Sn
0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5

Sn-Ag-Cu-Pb System

Vendor A Std.			Vendor F Std.			Vendor G Std.		
0.925	0.9338	(Sn)	0.925	0.9338	(Sn)	0.925	0.9338	(Sn)
0.033	0.0033	(Pb)	0.033	0.0033	(Pb)	0.033	0.0033	(Pb)
0.037	0.0501	Ag_3Sn	0.037	0.0501	Ag_3Sn	0.037	0.0501	Ag_3Sn
0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5

Sn-Ag-Cu System

Vendor A 3X			Vendor F 3X			Vendor G 3X		
0.954	0.9321	(Sn)	0.954	0.9321	(Sn)	0.953	0.9307	(Sn)
0.041	0.0551	Ag_3Sn	0.041	0.0551	Ag_3Sn	0.042	0.0565	Ag_3Sn
0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5

Sn-Ag-Cu-Pb System

Vendor A 3X			Vendor F 3X			Vendor G 3X		
0.923	0.9310	(Sn)	0.924	0.9324	(Sn)	0.923	0.9310	(Sn)
0.033	0.0034	(Pb)	0.033	0.0034	(Pb)	0.033	0.0034	(Pb)
0.039	0.0528	Ag_3Sn	0.038	0.0514	Ag_3Sn	0.039	0.0528	Ag_3Sn
0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5

2512 RESISTOR - PHASE MASS FRACTIONS

Sn-Ag-Cu System

Vendor A Std.	Mass Fraction		Vendor F Std.	Mass Fraction		Vendor G Std.	Mass Fraction	
0.963	0.9444	(Sn)	0.961	0.9416	(Sn)	0.963	0.9444	(Sn)
0.032	0.0428	Ag_3Sn	0.034	0.0456	Ag_3Sn	0.032	0.0428	Ag_3Sn
0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5

Sn-Pb-Ag System

Vendor A Std.			Vendor F Std.			Vendor G Std.		
0.638	0.5832	(Sn)	0.637	0.5818	(Sn)	0.638	0.5832	(Sn)
0.359	0.4130	(Pb)	0.359	0.4131	(Pb)	0.359	0.4130	(Pb)
0.003	0.0037	Ag_3Sn	0.004	0.0051	Ag_3Sn	0.003	0.0037	Ag_3Sn

Sn-Ag-Cu System

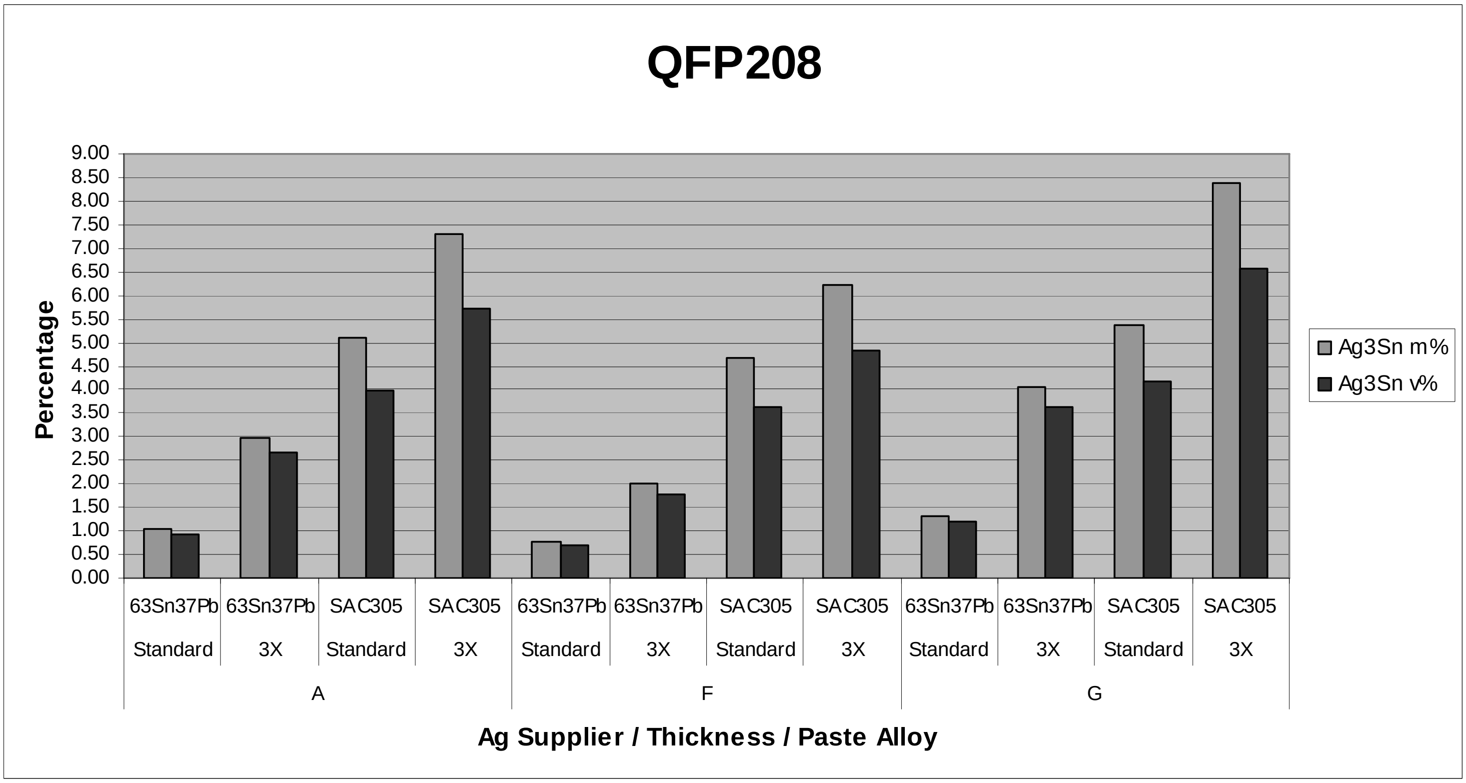
Vendor A 3X			Vendor F 3X			Vendor G 3X		
0.944	0.9184	(Sn)	0.949	0.9252	(Sn)	0.944	0.9184	(Sn)
0.051	0.0688	Ag_3Sn	0.046	0.0620	Ag_3Sn	0.051	0.0688	Ag_3Sn
0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5	0.005	0.0128	Cu_6Sn_5

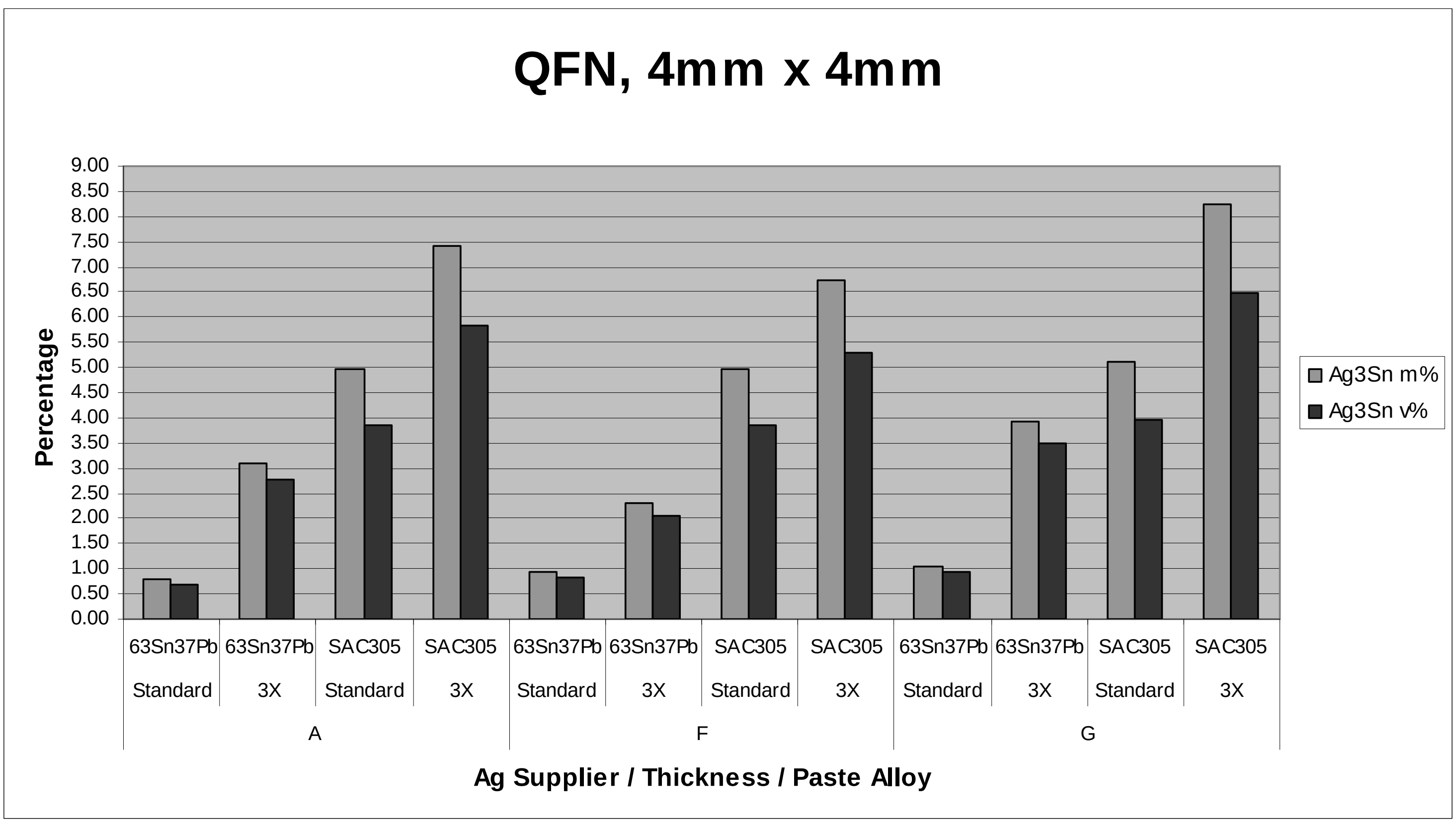
Sn-Pb-Ag System

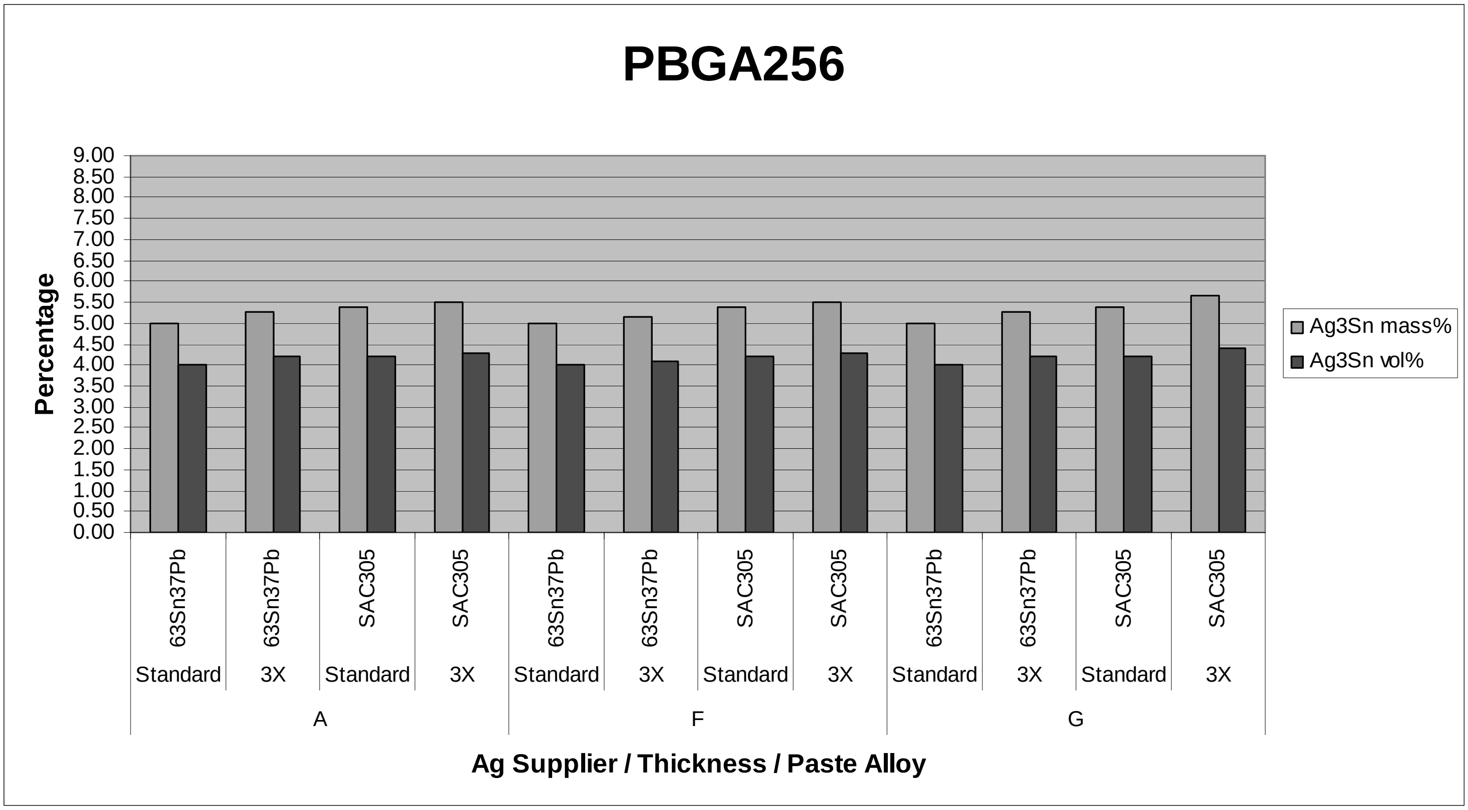
Vendor A 3X			Vendor F 3X			Vendor G 3X		
0.626	0.5654	(Sn)	0.629	0.5698	(Sn)	0.626	0.5654	(Sn)
0.354	0.4077	(Pb)	0.355	0.4087	(Pb)	0.354	0.4077	(Pb)
0.020	0.0270	Ag_3Sn	0.016	0.0215	Ag_3Sn	0.020	0.0270	Ag_3Sn

Component	ImAg Vendor	ImAg Thick.	Paste Alloy	Sn m%	Sn v%	Pb m%	Pb v%	Ag_3Sn m%	Ag_3Sn v%	Cu_6Sn_5 m%	Cu_6Sn_5 v%
	A	Standard	63Sn37Pb	57.11	65.30	41.84	33.75	1.06	0.94	0.00	0.00
		3X	63Sn37Pb	55.74	63.94	41.28	33.41	2.97	2.65	0.00	0.00
		Standard	SAC305	93.62	94.83	0.00	0.00	5.10	3.97	1.28	1.20
		3X	SAC305	91.43	93.09	0.00	0.00	7.29	5.70	1.28	1.20
	F	Standard	63Sn37Pb	57.26	65.46	41.96	33.84	0.78	0.69	0.00	0.00
QFP208		3X	63Sn37Pb	56.49	64.68	41.50	33.53	2.01	1.79	0.00	0.00
		Standard	SAC305	94.03	95.16	0.00	0.00	4.69	3.65	1.28	1.20
		3X	SAC305	92.52	93.96	0.00	0.00	6.20	4.84	1.28	1.20
	G	Standard	63Sn37Pb	56.95	65.15	41.72	33.67	1.33	1.18	0.00	0.00
		3X	63Sn37Pb	54.99	63.18	40.95	33.19	4.06	3.63	0.00	0.00
		Standard	SAC305	93.34	94.61	0.00	0.00	5.38	4.19	1.28	1.20
		3X	SAC305	90.33	92.21	0.00	0.00	8.39	6.58	1.28	1.21
	A	Standard	63Sn37Pb	57.64	65.82	41.57	33.49	0.78	0.69	0.00	0.00
		3X	63Sn37Pb	56.11	64.27	40.78	32.96	3.11	2.77	0.00	0.00
		Standard	SAC305	93.75	94.94	0.00	0.00	4.97	3.87	1.28	1.20
		3X	SAC305	91.29	92.98	0.00	0.00	7.43	5.82	1.28	1.20
	F	Standard	63Sn37Pb	57.63	65.79	41.45	33.39	0.92	0.82	0.00	0.00
QFN		3X	63Sn37Pb	56.71	64.87	41.00	33.09	2.29	2.04	0.00	0.00
		Standard	SAC305	93.75	94.94	0.00	0.00	4.97	3.87	1.28	1.20
		3X	SAC305	91.97	93.52	0.00	0.00	6.75	5.27	1.28	1.20
	G	Standard	63Sn37Pb	57.48	65.65	41.46	33.41	1.06	0.94	0.00	0.00
		3X	63Sn37Pb	55.38	63.55	40.69	32.94	3.93	3.51	0.00	0.00
		Standard	SAC305	93.62	94.83	0.00	0.00	5.10	3.97	1.28	1.20
		3X	SAC305	90.47	92.32	0.00	0.00	8.25	6.47	1.28	1.21
	A	Standard	63Sn37Pb	93.38	95.76	0.33	0.24	5.01	4.00	1.28	0.00
		3X	63Sn37Pb	93.10	95.54	0.34	0.25	5.28	4.22	1.28	0.00
		Standard	SAC305	93.34	94.61	0.00	0.00	5.38	4.19	1.28	1.20
		3X	SAC305	93.21	94.51	0.00	0.00	5.51	4.29	1.28	1.20
	F	Standard	63Sn37Pb	93.38	95.76	0.33	0.24	5.01	4.00	1.28	0.00
PBGA256		3X	63Sn37Pb	93.24	95.65	0.34	0.25	5.14	4.10	1.28	0.00
		Standard	SAC305	93.34	94.61	0.00	0.00	5.38	4.19	1.28	1.20
		3X	SAC305	93.21	94.51	0.00	0.00	5.51	4.29	1.28	1.20
	G	Standard	63Sn37Pb	93.38	95.76	0.33	0.24	5.01	4.00	1.28	0.00
		3X	63Sn37Pb	93.10	95.54	0.34	0.25	5.28	4.22	1.28	0.00
		Standard	SAC305	93.34	94.61	0.00	0.00	5.38	4.19	1.28	1.20
		3X	SAC305	93.07	94.40	0.00	0.00	5.65	4.40	1.28	1.20
	A	Standard	63Sn37Pb	58.32	66.46	41.30	33.21	0.37	0.33	0.00	0.00
		3X	63Sn37Pb	56.54	64.69	40.77	32.91	2.70	2.40	0.00	0.00
		Standard	SAC305	94.44	95.48	0.00	0.00	4.28	3.33	1.28	1.19
		3X	SAC305	91.84	93.42	0.00	0.00	6.88	5.38	1.28	1.20
	F	Standard	63Sn37Pb	58.18	66.32	41.31	33.22	0.51	0.45	0.00	0.00
2512 Resistor		3X	63Sn37Pb	56.98	65.13	40.87	32.96	2.15	1.91	0.00	0.00
		Standard	SAC305	94.16	95.26	0.00	0.00	4.56	3.55	1.28	1.19
		3X	SAC305	92.52	93.96	0.00	0.00	6.20	4.84	1.28	1.20
	G	Standard	63Sn37Pb	58.32	66.46	41.30	33.21	0.37	0.33	0.00	0.00
		3X	63Sn37Pb	56.54	64.69	40.77	32.91	2.70	2.40	0.00	0.00
		Standard	SAC305	94.44	95.48	0.00	0.00	4.28	3.33	1.28	1.19
		3X	SAC305	91.84	93.42	0.00	0.00	6.88	5.38	1.28	1.20

CHARTS OF DATA



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2.00
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1.00
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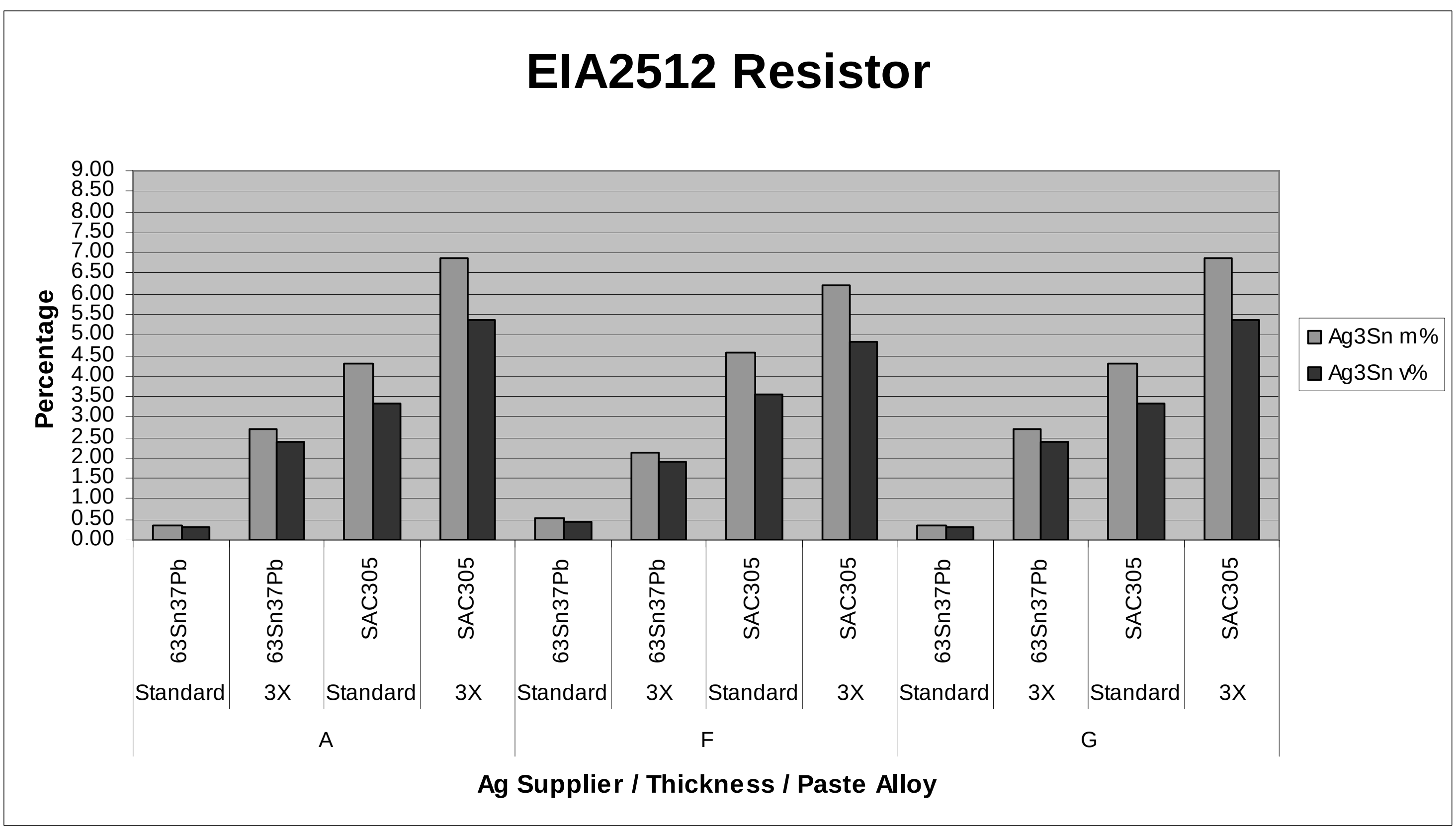
Standard
3X
A
F
G
Ag Supplier / Thickness / Paste Alloy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2.00
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1.00
0.50
0.00
Ag3Sn m%
Ag3Sn v%
63Sn37Pb
SAC305
Standard
3X
A
F
G
Ag Supplier / Thickness / Paste Alloy

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